Permeation of PE 100 pipe material

KWR 2019.043 | 3 May 2019

Author(s)
Alex Hockin

Project number
402631

Project manager
ing. Ton van Leerdam

More information
Alex Hockin, MSc.
T +31306069620
E alexandra.hockin@kwrwater.nl

Summary

Nederlands: Uit deze literatuurstudie volgt dat er slechts zeer beperkt onderzoek naar de permeatie van polyethyleen (PE) 100-pijpleidingen is gedaan. Er zijn geen studies in de literatuur gevonden die specifiek gekeken hebben naar de permeatie van verontreinigingen in waterige oplossingen in PE 100-materiaal. Er zijn een paar studies gevonden over de permeatie van PE-pijpleidingen voor aardgas die specifiek de permeatie van PE 100 tot PE 80 vergeleken. Sommige studies hebben de relatie tussen kristalliniteit en diffusie onderzocht, omdat diffusie optreedt via het amorfe (niet-kristallijne) deel van HDPE-materialen. PE 100 is een meer kristallijn materiaal dan PE80 en als kristalliniteit toeneemt is aangetoond dat diffusie afneemt. De exacte relatie tussen kristalliniteit en diffusie, en de afhankelijkheid van andere parameters zoals tortuosity, is echter complex en er is meer onderzoek nodig.

English: There is limited research into the permeation of polyethylene (PE) 100 pipelines. No studies in the literature were found which specifically looked at the permeation of contaminants in aqueous solutions in PE 100 material. A few studies were found on the permeation of PE pipelines for natural gas which specifically compared the permeation of PE 100 to PE 80. Some studies have researched the relationship between crystallinity and diffusion, as diffusion occurs through the amorphous (non-crystalline) region of HDPE materials. PE 100 is a more crystalline material than PE 80 and as crystallinity increased diffusion has been shown to decrease. However, the relationship between crystallinity and diffusion, and the dependence on other parameters such as tortuosity, is complex and more research is needed.

Contents

1 Background and Literature Search

High density polyethylene (HDPE) is frequently classified is by the long-term strength. PE 100 has a minimum required strength of 10 MPa while PE 80 has minimum required strength of 8 MPa (Ref XX). There is increasing interest in using PE 100 for pipelines and the research question was how does the permeation of PE 100 compare to permeation of PE 80. A limited literature review of the Scopus, Web of Science and Google Scholar databases was performed to find studies related to the permeation of PE 100. The majority of articles related to PE 100 concerned the mechanical and material properties of PE 100 pipelines (e.g. strength, crack resistance, impact resistance etc). There were limited studies which the permeatin of PE 80 and PEW 100 pipelines for natural gas. However, no studies were found on the aqueous permeation of PE 100 pipe materials. Aqueous permeation studies were primarily on geomembrane, for example for use in landfill liners, and most permeation studies did not give specific material properties of the HDPE tested (e.g. density, strength designation/type, crystallinity etc.). There were a limited number of studies which examined the relationship between crystallinity and permeability, diffusion and partitioning, however no simple and robust empirical relationship yet exists.

2 Permeation and Crystallinity

Islam and Rowe (2009) looked at the relationship between crystallinity, diffusion and partitioning in HDPE aged geomembranes. The authors found that as the HDPE aged, the crystallinity increased. Chemical specific relationships between crystallinity and diffusion, partitioning and permeation were established, see Table 7 in source. Vittoria (1995) studied the relationship between crystallinity, sorption and diffusion in both LDPE and HDPE. When the sorption was normalized to the amorphous area in samples (the non-crystalline portion of the PE) no change in sorption was observed for increasing crystallinity. However, no simple relationship was found between crystallinity and diffusion. Instead a transition zone between 50-60% crystallinity was observed. Rowe et al. (2012) studied the crystallinity in HDPE and fluorinated HDPE (f-HDPE). F-HDPE is more crystalline than HDPE and also showed decreased diffusion as a result. Lützow et al. (1999) found that diffusion and solubility of contaminants in the polymer decreased while tortuosity increased with increasing crystallinity. A decrease in diffusion and solubility and increase in tortuosity all lead to a decreased mass flux through higher crystalline PE materials. In summary, there is an apparent relationship between increasing crystallinity in HDPE and the permeability. Further research is required to establish an empirical relationship between increased crystallinity in PE 100 compared to PE 80 and the resulting changes in permeability parameters.

3 PE 100 and Permeability of Natural Gas Pipelines

Few studies have compared the permeation of PE 100 pipelines to PE 80 pipelines for natural gas. However, no studies were found for permeation of aqueous contaminants into PE 100. Klopffer et al. (2014) studied natural gas transport in PE 100 pipelines. The authors also looked into the effects of mixtures of gasses (natural gas and hydrogen) and found no mixture effects on permeation. The authors also previously worked on PE 80, however the references are to conference proceedings so there is limited or no reporting of permeability coefficients. See Foulc and Klopffer (2006), Klopffer and Flaconnèche (2008).

4 References

References include both references in the text (bold) and all references consulted.

4.1 Permeability and Crystallinity

Aminabhavi, T. M., & Naik, H. G. (1999). Sorption/desorption, diffusion, permeation and swelling of high density polyethylene geomembrane in the presence of hazardous organic liquids. Journal of Hazardous Materials, 64(3), 251–262. https://doi.org/10.1016/S0304-3894(98)00183-6

Cheng, C.-L. (2009). Permeation of organic compounds through ductile iron pipe gaskets. Iowa State University.

Clermont-ferrand, P., Pascal, U. B., & Universitaire, C. (n.d.). Surface Degradation and Crystallinity Changes in HDPE-100 Pipe Subjected to Chemical Aggressive Environments. Physics, 1–6.

Duncan, B., Urquhart, J., & Roberts, S. (2005). Review of Measurement and Modelling of Permeation and Diffusion in Polymers. Retrieved from http://resource.npl.co.uk/materials/polyproc/iag/october2005/depc%7B_%7Dmpr%7B_%7D012.pdf

Eun, J., Tinjum, J. M., Benson, C. H., & Edil, T. B. (2018). Equivalent Transport Parameters for Volatile Organic Compounds in Coextruded Geomembrane–Containing Ethylene-Vinyl Alcohol. Journal of Geotechnical and Geoenvironmental Engineering, 144(7), 04018040. https://doi.org/10.1061/(asce)gt.1943-5606.0001888

Faupel, F., Willecke, R., & Thran, A. (1998). Diffusion of metals in polymers. Materials Science and Engineering R: Reports, 22(1), 1–55. https://doi.org/10.1016/S0927-796X(97)00020-X

Ferhoum, R. (2014). Analysis of Thermal Ageing Effect (Hold Time - Crystallinity Rate - Mechanical Property) on High Density Polyethylene (HDPE). International Journal of Materials Science and Applications, 2(3), 109. https://doi.org/10.11648/j.ijmsa.20130203.17

Fernandez, L. A., Macfarlane, J. K., Tcaciuc, A. P., & Gschwend, P. M. (2009). Measurement of freely dissolved PAH concentrations in sediment beds using passive sampling with low-density polyethylene strips. Environmental Science and Technology, 43(5), 1430–1436. https://doi.org/10.1021/es802288w

Flaconnèche, B., Martin, J., & Klopffer, M. H. (2001). Permeability, Diffusion and Solubility of Gases in Polyethylene, Polyamide 11 and Poly(vinylidene fluoride) Polymer Characteristics. Oil & Gas Science and Technology-Rev. IFP, 56(3), 261–278. Retrieved from https://ogst.ifpenergiesnouvelles.fr/articles/ogst/pdf/2001/03/flaconneche2_v56n3.pdf

Foulc, Klopffer, F. (2006). Durability and transport properties of polyethylene pipes for distributing mixtures of hydrogen and natural gas. Whec, (June), 1–6.

Friess, K., Jansen, J. C., Vopička, O., Randová, A., Hynek, V., Šípek, M., … Drioli, E. (2009). Comparative study of sorption and permeation techniques for the determination of heptane and toluene transport in polyethylene membranes. Journal of Membrane Science, 338(1–2), 161–174. https://doi.org/10.1016/j.memsci.2009.04.030

Galchun, A., Korab, N., Kondratenko, V., Demchenko, V., Shadrin, A., Anistratenko, V., & Iurzhenko, M. (2015). Nanostructurization and thermal properties of polyethylenes' welds. Nanoscale Research Letters, 10(1), 1–6. https://doi.org/10.1186/s11671-015-0832-4

Ghaemy, M., Hadjmohammadi, M. R., & Tabaraki, R. (2000). Study of Crystallinity of High-density Polyethylene by Inverse Gas Chromatography. Iranian Polymer Journal (English Edition), 9(2), 117–124. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-0348246461&partnerID=40&md5=1a2937593c4e913074939845954479c0

Howell, B. F., McCrackin, F. L., & Wang, F. W. (1985). Fluorescence measurements of the diffusion coefficient for butylated hydroxyanisole in low-density polyethylene. Polymer, 26(3), 433–436. https://doi.org/10.1016/0032-3861(85)90207-1

Islam, M. Z., & Rowe, R. K. (2009). Permeation of BTEX through Unaged and Aged HDPE Geomembranes. Journal of Geotechnical and Geoenvironmental Engineering, 135(8), 1130–1140. https://doi.org/10.1061/(asce)gt.1943-5606.0000056

Joo, J. C., Kim, J. Y., & Nam, K. (2004). Mass transfer of organic compounds in dilute aqueous solutions into High Density Polyethylene Geomembranes. Journal of Environmental Engineering, 130(2), 175–183.

Klopffer, M.-H., & Flaconnèche, B. (2008). TRANSPORT PROPERTIES OF POLYMER PIPES FOR DISTRIBUTING MIXTURES OF HYDROGEN AND NATURAL GAS : DEVELOPMENT OF A NEW EXPERIMENTAL METHOD. In Plastic Pipes XIV September 22-24 (pp. 1–7).

Klopffer, M.-H., Berne, P., & Espuche, É. (2014). Development of Innovating Materials for Distributing Mixtures of Hydrogen and Natural Gas. Study of the Barrier Properties and Durability of Polymer Pipes. Oil & Gas Science and Technology – Revue d'IFP Energies Nouvelles, 70(2), 305–315. https://doi.org/10.2516/ogst/2014008

Lohmann, R. (2012). Critical review of low-density polyethylene's partitioning and diffusion coefficients for trace organic contaminants and implications for its use as a passive sampler. Environmental Science and Technology, 46(2), 606–618. https://doi.org/10.1021/es202702y

Lützow, N., Tihminlioglu, A., Danner, R. P., Duda, J. L., De Haan, A., Warnier, G., & Zielinski, J. M. (1999). Diffusion of toluene and n-heptane in polyethylenes of different crystallinity. Polymer, 40(10), 2797–2803. https://doi.org/10.1016/S0032-3861(98)00473-X

Mao, F., Ong, S. K., & Gaunt, J. A. (2015). Modeling benzene permeation through drinking water high density polyethylene (HDPE) pipes. Journal of Water and Health, 13(3), 758–772. https://doi.org/10.2166/wh.2015.183

Pircheraghi, G., Sarafpour, A., Rashedi, R., Afzali, K., & Adibfar, M. (2017). Correlation between rheological and mechanical properties of black PE100 compounds - effect of carbon black masterbatch. Express Polymer Letters, 11(8), 622–634. https://doi.org/10.3144/expresspolymlett.2017.60

Rowe, R. K., Mukunoki, T., & Lindsay, H. (2012). Effect of Temperature on Btex Permeation Through Hdpe and Fluorinated Hdpe Geomembranes. Soils and Foundations, 51(6), 1103–1114. https://doi.org/10.3208/sandf.51.1103

Rowe, R. K., Saheli, P. T., & Rutter, A. (2016). Partitioning and diffusion of PBDEs through an HDPE geomembrane. Waste Management, 55, 191–203. https://doi.org/10.1016/j.wasman.2016.05.006

Sangam, H. P., & Rowe, R. K. (2001). through HDPE geomembranes $. Geotextiles and Geomembranes, 19, 329–357.

Satkowski, M. M. (1990). The crystallization and morphology of polyethylene and its blends. University of Massachusetts Amherst. https://doi.org/10.1007/s11458-010-0211-8

Stadler, F. J., Takahashi, T., & Yonetake, K. (2009). Lattice sizes, crystallinities, and spacing between amorphous chains - characterization of ethene-/α-olefin copolymers with various comonomers and comonomer contents measured by wide angle X-ray scattering. E-Polymers, (040), 1–19.

Vittoria, V. (1995). Influence of the crystallinity on the transport properties of polyethylene. Journal of Materials Science, 30(15), 3954–3958. https://doi.org/10.1007/BF01153962

Whelton, A. J. (2010). Contaminate transport in silane crosslinked HDPE, (February), 227–237.

4.2 PE 100 and Permeability of Natural Gas Pipelines

Ferhoum, R. (2014). Analysis of Thermal Ageing Effect (Hold Time - Crystallinity Rate - Mechanical Property) on High Density Polyethylene (HDPE). International Journal of Materials Science and Applications, 2(3), 109. https://doi.org/10.11648/j.ijmsa.20130203.17

Foulc, Klopffer, F. (2006). Durability and transport properties of polyethylene pipes for distributing mixtures of hydrogen and natural gas. Whec, (June), 1–6.

Galchun, A., Korab, N., Kondratenko, V., Demchenko, V., Shadrin, A., Anistratenko, V., & Iurzhenko, M. (2015). Nanostructurization and thermal properties of polyethylenes' welds. Nanoscale Research Letters, 10(1), 1–6. https://doi.org/10.1186/s11671-015-0832-4

Hermkens, R. J. M., Colmer, H., & Ophoff, H. A. (2018). Modern Pe Pipe Enables the Transport of Hydrogen. Proceedings of the 19th Plastic Pipes Conference, 2018, 1–12.

Klopffer, M.-H., & Flaconnèche, B. (2008). TRANSPORT PROPERTIES OF POLYMER PIPES FOR DISTRIBUTING MIXTURES OF HYDROGEN AND NATURAL GAS : DEVELOPMENT OF A NEW EXPERIMENTAL METHOD. In Plastic Pipes XIV September 22-24 (pp. 1–7).

Klopffer, M.-H., Berne, P., & Espuche, É. (2014). Development of Innovating Materials for Distributing Mixtures of Hydrogen and Natural Gas. Study of the Barrier Properties and Durability of Polymer Pipes. Oil & Gas Science and Technology – Revue d'IFP Energies Nouvelles, 70(2), 305–315. https://doi.org/10.2516/ogst/2014008

Pircheraghi, G., Sarafpour, A., Rashedi, R., Afzali, K., & Adibfar, M. (2017). Correlation between rheological and mechanical properties of black PE100 compounds - effect of carbon black masterbatch. Express Polymer Letters, 11(8), 622–634. https://doi.org/10.3144/expresspolymlett.2017.60

Zhang, Y., & Jar, P. Y. B. (2016). Comparison of Mechanical Properties Between PE80 and PE100 Pipe Materials. Journal of Materials Engineering and Performance, 25(10), 4326–4332. https://doi.org/10.1007/s11665-016-2274-2

Year of publishing
2019

More information
Alex Hockin, MSc.
T +31306069620
E alexandra.hockin@kwrwater.nl

Postbus 1072
3430 BB Nieuwegein
The Netherlands

T +31 (0)30 60 69 511
F +31 (0)30 60 61 165
E info@kwrwater.nl
I www.kwrwater.nl