Polymer Testing 40 (2014) 280–285

Contents lists available at ScienceDirect

Polymer Testing

journal homepage: www.elsevier.com/locate/polytest

Material performance

Chemical and pressure stress resistance of polymer films

Dmitrij Laaber [1], Hans-Jörg Bart [*]

Chair of Separation Science, TU Kaiserslautern, P. O. 3049, 67653 Kaiserslautern, Germany

ARTICLE INFO

Article history:
Received 8 August 2014
Accepted 29 September 2014
Available online 7 October 2014

Keywords:
Polymer films
Organic solvents
Chemical resistance
Mechanical testing

ABSTRACT

The usability of polymer films in heat exchangers used in the chemical industry for solvent condensation was evaluated. The mechanical strength and chemical resistance of two high performance polymer films (a polyimide film and a PTFE-glass fibre compound) were investigated at temperatures up to 90°C with constant as well as pulsating pressure loads of 6 bar. The influence of four organic solvents (toluene, hexane, heptane, tetrahydrofurane (THF)) and hot water on the mechanical stability was determined. It could be shown that toluene and THF caused a major weakening of the material, while water, hexane and heptane barely affected the films. The best results showed the PTFE-glass fibre compound having a two monthly durability at constant pressure exposure for all the solvents used, except THF.

1. Introduction

Heat exchangers are one of the most commonly used system units in all kinds of industry. Apart from their different application purposes (heat transfer without a phase change, condensation and boiling), they can be classified by their design, flow directions and materials. The most preferred material group are without doubt metals, such as steel, aluminium and copper alloys. These materials combine very good mechanical stability with excellent heat transfer rates. However, for some niche applications metals are not appropriate, e.g. handling of highly corrosive fluids such as acids or alkaline solutions. For these cases, the most commonly used materials are glass, ceramics or polymers. Their chemical resistance is much higher than that of metals, but the heat conductivity coefficients are lower. In the case of polymers, these values are below 0.5 W/m^2 K while for most metals the corresponding values exceed 100 W/m^2 K. The low prices of polymers are an additional advantage compared with glass or ceramics. Since the heat transfer coefficients in polymers are very low, the material has to be very thin in order to achieve a competitive heat exchanger performance. Hence, the proposed heat exchanger uses a thin polymer film of 75–150 µm as the heat transfer surface comparable to 1.5 mm stainless steel. Due to the high flexibility of the films and the presence of organic solvents, the chemical resistance and the mechanical stability have to be proven, such as the combination of high mechanical stress with the presence of water and organic solvents at high temperatures. The operating conditions of the heat exchanger for the specific application of condensation of organic solvents are given in Table 1.

Most manufacturers of polymers, however, do not provide appropriate information on the mechanical, chemical and thermal behaviour of their products. Concerning the chemical stability, most of the data that can be found only contains results from testing at temperatures of about 20 to 25°C. (e.g. [2]) Rarely, results for testing at 50°C can be found [3]. With regard to the tensile strength of the films, mostly results of tests in dry air and at temperatures of around 20°C can be retrieved. No testing procedures or test results for the combination of the impact of an organic solvent with a high mechanical stress at relatively high

* Corresponding author. Tel.: +49 631 205 2117.
E-mail addresses: dmitrij.laaber@mv.uni-kl.de (D. Laaber), bart@mv.uni-kl.de (H.-J. Bart).
[1] Tel.: +49 631 205 2124.

http://dx.doi.org/10.1016/j.polymertesting.2014.09.018
0142-9418/

Table 1
Operating conditions for condensation of organic solvents.

Temperature (organic side)	60°C–100°C	depending on the solvent used
Pressure (organic side)	<1 bar	
Temperature (cooling water)	15°C–23°C	depending on weather conditions
Pressure (cooling water)	up to 6 bar	4 bar at standard conditions, 6 bar for start-up

temperatures of about 100°C could be found. Serban et al. [7] tested samples of semi-crystalline polymers at a maximum temperature of 50°C.

Due to the flexibility of the film, it is necessary to have it stabilised by an appropriate grid-like structure. A simplified example of a possible construction is given in Fig. 1. It shows a polymer film heat exchanger module with two polymer films which separate the fluids. For this application, the overpressure on the cooling water side is about 4–6 bar. The width of the milled flow channels can be varied with respect to the pressure and the mechanical properties of the film used. The flow channel width used here was 10 mm and is the basis of the test rig dimensions described below.

2. Methods and materials

2.1. Tested polymers

Several polymers used for production of films were considered as possible materials for the developed heat exchanger. The main criteria for the selection were chemical resistance, mechanical strength and thermal stability for the given temperature range. After some preliminary tests and literature research, two high-performance polymers, polyimide (PI) and a polytetrafluoroethylene-glass fibre compound (PTFE-GF) were selected for detailed investigation. Because of the very weak mechanical strength of pure PTFE [4], this film is reinforced by a glass fibre mesh. The tested thickness of the polyimide films was 75 μm and approx. 150 μm for the PTFE-GF because of the glass fibre mesh.

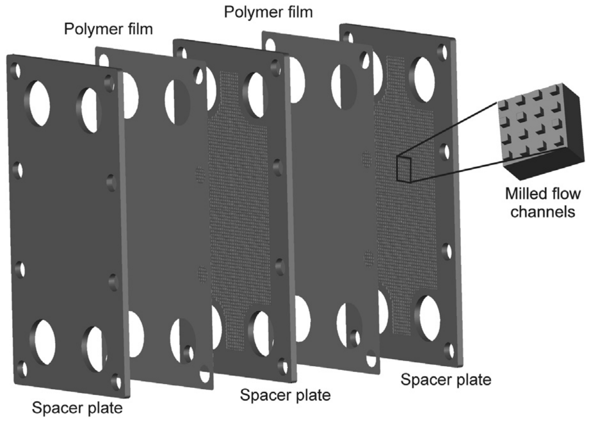

Fig. 1. Simplified sketch of a polymer film heat exchanger.

Polyimide represents the group of polymers developed for high temperature applications. The polyimide Kapton® HN film (supplied by DuPont [5]) used for this work is synthesised by condensation of pyromellitic dianhydride and 4,4'-oxydianiline. Common applications for this polymer are the insulation of electronic parts, membranes or diaphragms. According to the manufacturer, Kapton® HN has outstanding chemical resistance combined with very high mechanical stability, as indicated in Table 2.

Polytetrafluoroethylene (PTFE), also often called Teflon®, which is a trademark of DuPont, represents the group of fluor containing polymers. These polymers were also developed for high temperature applications. PTFE has a very low mechanical stability but very good sliding and thermal properties as well as a very good chemical resistance [4]. Therefore, it is very often used for plain bearings, but also for a wide range of applications with aggressive chemicals and high temperatures.

2.2. Experimental setup

As shown in Fig. 2, the test rig consists of a pressure pipe with a mounting plug, connected to a compressed air supply. The pressure in the pipe can be adjusted by means of a manual pressure regulator to between 0 and 6 bar. A magnetic valve which is controlled by a time relay is also attached to the pipe. This enables testing with a pulsating load. The on-off periods can be set individually from 3 to 300 seconds. The polymer film sample is clamped in a mounting plug by a lock nut, between a blind plug and an O-ring, as shown in Fig. 2. The self-sealing screw thread of the nut ensures the leak-tightness of the system. The blind plug has a borehole in the centre. On the film sample side the borehole has either a quadratic opening with a side length of 10 mm or a cylindrical opening. The various blind plug openings represent the free film space between the supporting structure elements depending on the support type of the heat exchanger.

The temperature in the heating circuit can be adjusted to up to 90°C with water or, if other heat transfer fluids are used, even higher temperatures. For the investigation of the impact of organic solvents, the pressure pipe is filled with the corresponding liquid, the upside-down position of the mounting plug ensures the sample stays in permanent contact with the solvent. The deformation change of the polymer is determined by measuring the curvature height.

Table 2
Physical data of the investigated polymers [1,4,5].

	PTFE (blocks)	Polyimide (blocks)
Max. operating temperature	>400°C	>400°C
Glass transition temperature	127	360°C–410°C
Tensile strength at 23–25°C	34.5 MPa	75–100 MPa
Elongation at break	375%	72%
Resistance to water	excellent	low affection of tensile strength (<10%)
Resistance to organic solvents	excellent	low affection of tensile strength (<10%)