Investigation of a conducting polymer O-ring seal for microvalves

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Summary *The gas-sealing properties of a novel electro-deposited poly(pyrrole) O-ring have been studied. The leakage flow rate through a polymer O-ring seal was determined using a vacuum system by measuring the change in the pressure dropped across it. The result suggested that the generalised leakage flow (q) through the poly(pyrrole) O-ring seal was proportional to the film thickness (d) and the film porosity. It was also found that the effectiveness of the polymer seal is increased by the application of an external load. This effect was most significant on the thickest poly(pyrrole) film of 2.7 μm.*

Keywords: *Poly(pyrrole) O-ring seal, thickness dependence, generalised flow, leakage rate, porosity*
Category: *2 (Materials and technology)*

1. Introduction

Although conducting polymers have been the subject of a large number of studies in different fields, for example as chemoresistor sensors [1], little work has been reported on their mechanical properties [2]. Novel properties of conducting polymers, such as their reproducibility, ability to be electro-deposited into small spaces in any shape and pattern [3], make them an attractive material for use in microengineering systems. This work is a continuation of preliminary studies being carried out by Warwick University to investigate the behaviour of the conducting polymers as electro-deposited seals in micro-valve systems [4].

2. Experimental

2.1 Test rig design

A low cost test rig has been designed and constructed to investigate the sealing properties of conducting polymer O-rings under different load forces. It measures leakage (rising pressure) into a partly-glass vacuum chamber through an electromechanical valve, controlled by commercial LabView™ software. The test rig consists of a stainless steel vacuum chamber (35 ml volume), a vacuum pump, a manual sealing valve and a digital pressure sensor to monitor the chamber pressure. A glass pentaprism with a 750 μm diameter through hole provided an ideal surface for the O-rings sealing contacts. Accurate alignment of the O-rings' centres over the hole was achieved using the pentaprism, a magnifying TV camera and an X-Y-Z positioner.

A solenoid with a saturated magnet attached to a spring beam provided a linearly controlled electromagnetic force to apply external pressure on the O-rings. This was achieved using a constant current source drive and a software program written in Labview. It supplied sufficient current for generating the desired magnetic field within the coil. Figure 1 illustrates the technical arrangement of the experimental test rig.

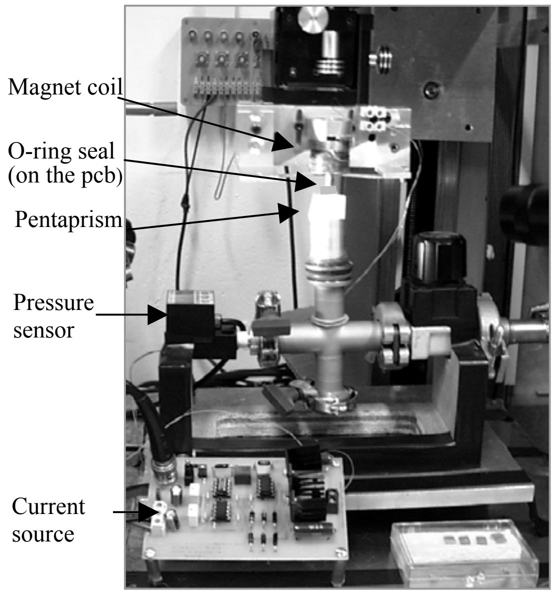

Figure 1. The photograph of the test rig designed to investigate the O-ring characteristic in vacuum condition.

2.2 Measurement procedure

Poly(pyrrole) with counterion 1-butane sulphonic acid (PPY-BSA)) was electrochemically deposited on the SRL 168 O-ring devices in the Chemistry department at Southampton University. Three different polymer thicknesses (1 μm, 2 μm and 2.7 μm) were used in the measurement. All testing was carried out under similar conditions at room temperature. The O-rings were subjected to a vacuum pressure of about 10^5 Pa each for leakage test. The rate of pressure change in the chamber was measured for different O-ring thickness, d.

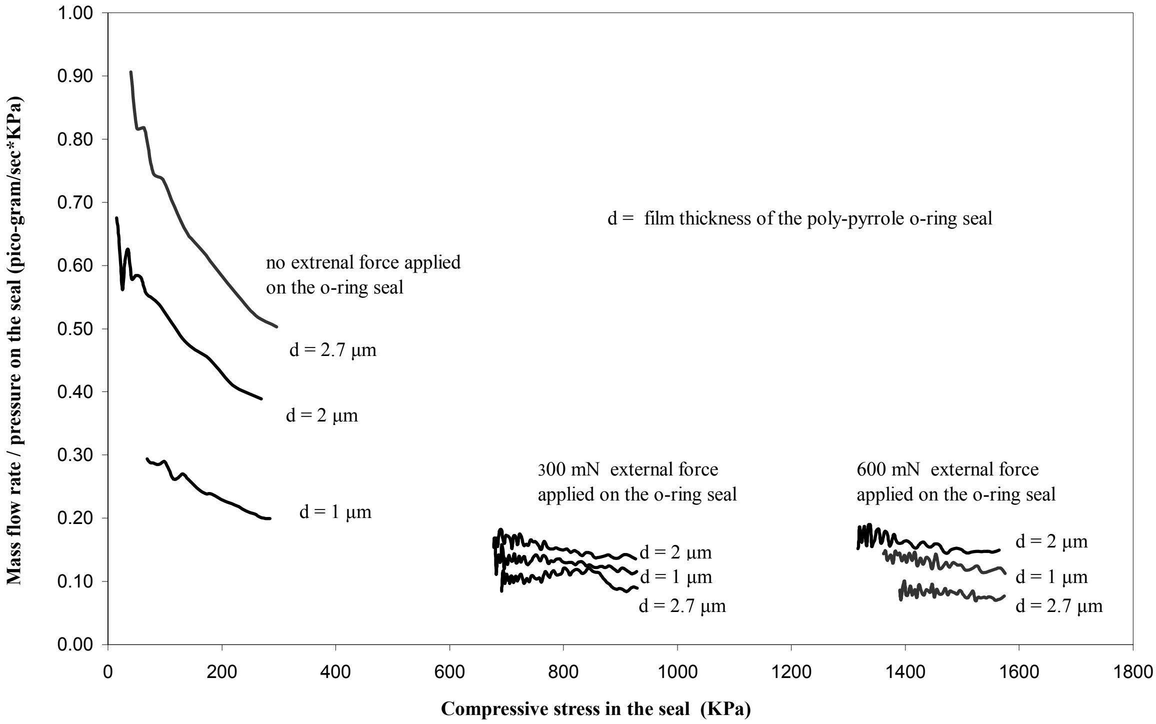

Figure 2. The effect of the closure force and the seal thickness on the leakage flow rate

Further experiments were carried out with the additional application of an external force to the O-rings of 300 mN and 600 mN, respectively. All the data were finally recorded and saved in a spreadsheet file using a Labview program.

3. Results and discussion

A simple mathematical model defines the leakage of a gas through a poly(pyrrole) O-ring as

$$\dot{q} = p_s \times 1/X$$

where $\dot{q}$ is the generalised flow, p_s is the differential pressure on the seal and X represents all the "resistive" parameters in the seal that have an effect on the leakage flow (e.g. average roughness, compressive stress, film porosity). Figure 2 illustrates the effect of the closure force and the film thickness on the seal resistivity (i.e. q/p_s). In natural seal conditions (i.e. no external force), the film thickness is almost inversely proportional to the resistivity ($d \propto 1/X$). This confirms that the leakage process is linear and partly through the pores within the polymer film. If thick films compress more, it does not overcome their greater porosity and surface roughness.

Applying external forces to the poly(pyrrole) seals increased the resistivity effect, improving the sealing property. The thickest film (2.7 µm) showed the best sealing action, while the middle one improved less with increased load. It appears that the external axial force on the thickest polymer seal (with the most pores) compresses the pores and hence restricts the leakage flow rate through the seal, but thinner films are too stiff for this to occur. We also expect that the application of an external force to control the leakage rate is more effective on less dense polymers (with more porosity). Thin films may be better if only natural sealing is used.

These findings may be considered as important factors in the design of an intelligent seal with controllable mechanism. The promising action with gases suggests that the seal will be very good with liquids and direct investigations are proceeding.

References

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