Chemical Engineering Science 60 (2005) 2621–2626

Chemical Engineering Science

www.elsevier.com/locate/ces

Experimental studies of biliquid capillary siphons

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Received 4 December 2003; accepted 7 December 2004

Abstract

The capillary siphon is a device capable of transporting a liquid from a higher level to a lower level by capillary action under gravity. The device is usually configured in an inverted U-shape with an intake end and a discharge end. However, to the authors' knowledge, the prior arts have not disclosed a process or apparatus that utilizes the capillary siphon action to transfer a liquid into a different liquid from a lower level to a higher level. In this paper, a porous medium, which preferentially has a higher wickability with respect to the first liquid than to the second liquid, is disposed in a siphon fashion with the first or intake end contacting the first liquid and the second or discharge end contacting the second liquid. A net amount of the first liquid was observed to be pumped into the second liquid. The aforementioned novel device functions as a passive pump, and could find applications in many systems such as portable direct methanol fuel cells and drug delivery systems. The device with these potential applications is termed as the "biliquid capillary siphon". The biliquid capillary siphon was successfully tested using several typical wick materials such as fiberglass, ceramic, polyethylene and PTFE under both dynamic and quasi-equilibrium states.

Keywords: Capillary siphon; Biliquid; Passive pump; Porous media; Transport processes

1. Introduction

The capillary siphon approach has been used for various purposes. Litt (1962) disclosed a water purification structure that could be used as a capillary siphon filter. A container at a higher level is filled with contaminated water, and purified water is collected in a container at a lower level. The wick in Litt's patent comprises a porous medium, which is sufficiently compacted without any appreciable passages, and serves merely as siphon conduits. Litt found that a water molecule would travel as much as 15 times as fast as an ion through the wick. Water would move upward and downward through the wick by capillary action and under gravity, leaving behind ions. The recovery of product water can continue until the ions begin to come through the wick. Then the wick can be lifted free and purged by flushing rejected ion from its surface. The wick can return to its working position when needed.

The invention by Swanson and Kelly (1977) is especially suitable for the removal of oil from an aqueous mixture. A wick capable of preferential sorption of oil is positioned in a siphon fashion with the intake end placed in the mixture and the discharge end positioned at least below the top of the liquid mixture level. The wick is preferentially sorptive of oil over water in the mixture. The oil is removed from mixture through a mechanism which resembles siphoning by the wick. The inventors stated that: "while there is no logical explanation as to why the sorbent materials (wick) will act like siphons and release liquid (oil) when placed in siphon relationship to the liquid to be sorbed, the fact remains that the phenomenon does in fact occur and this is a very important aspect of the present invention".

Acuna (1982) provided a process and apparatus for separating liquids and undissolved solids. "siphon filter" is used to describe the wick which is capable of transporting liquid from one level to a lower level by capillary action while substantially preventing the transportation of undissolved solids above a given size.

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doi:10.1016/j.ces.2004.12.015

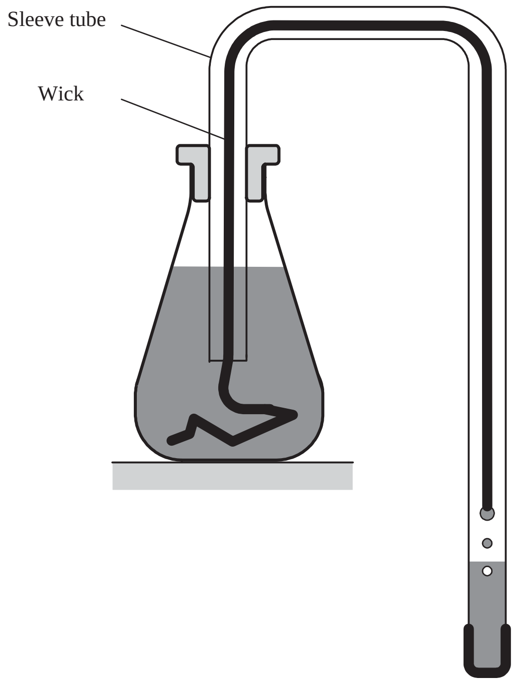

Fig. 1. A conventional capillary siphon.

Liang (1993) developed a capillary device for watering-plants. Such a device mainly comprises a water container hung over the upper edge of a flower pot and an absorbent wick extending from the water container to the bottom of the flower pot so that the water will flow into the soil from the flower pot by a capillary or combined capillary and siphon action.

From above-mentioned references, the most appreciable characteristics of the capillary siphon can be summarized as follows:

(1) capillary siphons can self-start;
(2) capillary siphons could be used as filters for separating liquids and undissolved solids;
(3) The wicks used by Swanson and Kelly (1977) and Acuna (1982) act as a semi-permeable membrane, which is permeable by the first liquid but not by the second. As a result, the first liquid penetrates through the wick and flows into the container at a lower level.

Utilization of the capillary siphon action to measure wickability of a porous medium has been reported by Harnett and Mehta (1984). The test procedure (Fig. 1) is as follows: a rectangular trip of the test fabric is used as a siphon by immersing one end in a reservoir of water or saline solution and allowing the liquid to drain from the other end placed into a collecting beaker. The amount of liquid transferred at successive time intervals can be determined by weighting the collecting beaker.

2. Liquid gradient distributions and uptake in wicks

To gain information on liquid transportation in wick materials, we have measured the liquid retention along vertically hung wicks with the lower end immersed in a reservoir of the liquid being tested. Prior to the experiments, all wicks were cleaned by rinsing in a 5% H_2O_2 solution at 50 °C, followed by three water rinses. Then these wicks were dried at 50 °C in an incubator for at least 24 h and cut into 25 cm long specimens. A small brass rod with a diameter of 0.6 cm was sewn to the end of each specimen to prevent it from curling during the test. The specimen was suspended vertically in a sealed tube with the tested liquid inside as shown in Fig. 2. The bottom end of the specimen was just submerged in the tested liquid. The tests were conducted at a room temperature of 20 °C for 48 h to establish an equilibrium state. The lid of the tube was then removed and the specimen was quickly cut into 5 cm long pieces. Each piece was then sealed in a plastic bag for weighting.

The bags used to hold the sample pieces were weighted before being used and then weighted with the specimen pieces still sealed inside. The difference between these two weights is referred to as the "wet" mass M_w of the piece. Specimens were removed from the plastic bags and dried thoroughly in an incubator, and then weighted again after drying. This second weight is referred to as the "dry" mass M_d of the piece. The liquid retention of the wick can be determined by the following equation:

$$R = \frac{M_w - M_d}{\rho M_d}, \tag{1}$$

where R(mL/g) is the liquid retention of the wick.

As shown in Fig. 3, the fiberglass wick has the highest liquid retention density when the liquid tested was 75% methanol aqueous solution. For pure methanol, the liquid distribution in the vertically hung fiberglass wick was nearly uniform. Liquid retention density was much lower for those liquids in which the methanol concentration is less than 50%. The characteristic height for a given piece is taken as the height of its midpoint above the liquid level during the test. Fig. 4 shows liquid uptake retention density of methanol aqueous solution in porous polyethylene wick. It is well-known that polyethylene is a hydrophobic material. The water retention density was nearly zero above the liquid level, which indicates no water uptake in the porous polyethylene.

3. Biliquid capillary siphon and its working mechanism

Fig. 5 shows a schematic sectional view of a biliquid capillary siphon. A strip of wick material is positioned in a siphon fashion so that its one end dips into a liquid and the other end dips into a different liquid. This configuration is different from the conversional capillary siphon described earlier in which only one liquid is involved in the liquid transportation process. We assume that two liquids are miscible and