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High resolution simultaneous dual liquid level measurement system with CMOS camera and FPGA hardware processor

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ABSTRACT

In this paper a new high precision automatic measurement system for liquid level measurement in membrane distillation application is presented. Membrane distillation (MD) is a relatively new process that is being investigated worldwide. It has some advantages in relation to other separation processes such as conventional distillation and reverse osmosis (RO), which are: high quality of distillate, low operating temperatures, low operating pressure, low power consumption allowing the use of alternative energy sources such as solar and geothermal energy.

For MD process it is necessary a very high precision system to measure the solution level in the reservoirs, able to detect changes smaller than 0.05 mm. This is due to the small fluxes through the membrane, and therefore it is necessary to detect the small changes produced in the liquid levels in the reservoirs. Until now such measurement has been made manually, by means of a cathetometer, but it resulted very uncomfortable. In order to overcome this issue, a high resolution and accuracy system (0.013 ± 0.008 mm), that makes automatic measurements of both reservoirs, cold and hot, is proposed. This system is based on a laser beam, assisted with a high resolution 3 Mpixels CMOS camera and a computer vision processor implemented in a FPGA, with a measurement rate up to 12 times per second.

1. Introduction

Membrane distillation (MD) [1] is a relatively new process that is being investigated worldwide. It has some advantages versus other separation processes such as conventional distillation and reverse osmosis (RO).

The main benefits of membrane distillation in relation to other conventional separation processes may be summarized as follows:

- High quality of distillate. Theoretically, 100% of ions, macromolecules, colloids, cells, and other non-volatile components are rejected.
- Low operating temperatures.
- Low-grade, waste and alternative energy sources such as solar and geothermal energy may be used.
- Low operating pressures.
- Less demands about membrane mechanical properties.
- Chemical interaction between membrane and process liquids is very small. The membrane acts merely as a support for the vapour liquid interface.

Driving force for the transport process is the vapour partial pressure gradient across the membrane. A temperature difference is imposed across the membrane, which results in a vapour pressure difference. The liquid–vapour equilibrium determines the separation process. The membrane itself produces no selection in the separation process.

There are different configurations for MD processes [2], depending on the way in which the partial pressure gradient in the vapour phase is established. Direct Contact MD (DCMD) [2], Osmotic MD (OMD) [3], Sweeping Gas MD (SGMD) [4], Vacuum MD (VMD) [5], and Air Gap MD (AGMD) [6,7].

In DCMD configuration the permeate side of the membrane is in direct contact with a cold aqueous solution (called permeate) and another solution at a higher temperature is brought into contact with the other side of the membrane (that is called feed). In this configuration the vapour condenses in contact with the cold side. The main problem of this configuration is the low efficiency in energy use. DCMD is the best suited for applications in which the major fluxing component is water, such as desalination or the concentration of aqueous solutions.

The membrane must not be wetted by the process liquids. This is an important limitation in MD processes. Therefore, the pressure difference at the interface must not overcome the liquid input pressure. If $\Delta P_{\mathrm{interface}}$ exceeds $\Delta P_{\mathrm{input}}$ the liquid can penetrate into and through the membrane pores. Once a pore has been penetrated

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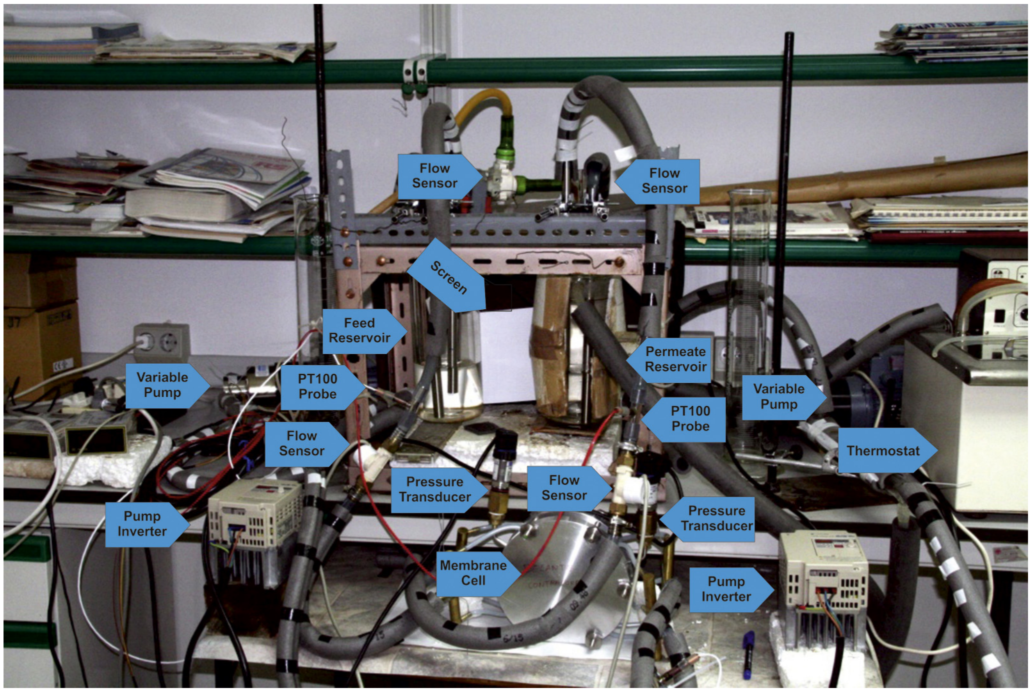

Fig. 1. Membrane distillation system.

it is said to be 'wetted' and the membrane must be completely dried and cleaned before the wetted pores can once again support a vapour–liquid interface. Wetted pores allow liquid to pass directly through the membrane, which can result in several problems depending on the type of MD being used and the liquid pressures. For example, in DCMD and AGMD, feed solution can flow directly across the membrane through the wetted pore, contaminating the permeate solution. If a large quantity of pores become wetted, permeate quality will deteriorate. Therefore, the goal of any MD system design should be to completely prevent pore wetting. This is one of the major restrictions in MD processes.

Different independent modes or mechanisms may be present in the gas transport through porous media, as follows:

- Free-molecule or Knudsen flow, in which the gas density is so low that collisions between molecules can be ignored compared to collisions of molecules with the walls of the porous medium or tube.
- Viscous flow, in which the gas acts as a continuous fluid driven by a pressure gradient, and molecule–molecule collisions dominate over molecule–wall collisions.
- Continuous diffusion, in which the different species of the mixture move relative to each other under the influence of concentration gradients, temperature gradients, or external forces. Here molecule-to-molecule collisions again dominate over molecule-to-wall collisions.
- Surface diffusion, in which molecules move along a solid surface in an adsorbed layer.

The experimental setup used in the DCMD experiments is shown in Fig. 1.

Feed and permeate solutions were contained in two double-wall reservoirs. These reservoirs have a volume capacity of approx. 1500 ml and has a 120 mm height without tube connections. The height variation during the experiments is 50 mm max. Both solutions were driven by variable flow pumps. The flow rate was measured with a liquid flow sensor set at the inlet and outlet of both semicells. The pressure was measured at both sides of the membrane inside of the cell, using digital pressure transducers. The temperature control was achieved using thermostats connected to the reservoirs. The temperature was measured at both sides of the membrane, at the inlet, inside and at the outlet of the cell, using Pt-100 probes. In order to improve the thermostatization process two heat exchangers were connected between the reservoirs and the thermostats (Fig. 2).

It is necessary a very high precision system to measure the solution level in the reservoirs, able to detect changes smaller than 0.05 mm. This is due to the small fluxes through the membrane, and therefore it is necessary to detect the small changes produced in the liquid levels in the reservoirs. Until now such measurement has been made manually, by means of a cathetometer, but it resulted very uncomfortable. This makes impossible the complete automation of the process. All remaining measurements such as, temperatures, flows, pressures have already been automated by means of a data acquisition system consisting of a Digital Multimeter Keithley 2700 and a 40-channel differential multiplexer module [8]. The flow sensors are made of a rotatory turbine with a pulsed output signal, whose frequency is proportional to the flow going through it. The pressure transducers have an analogical current output ranging 4–20 mA. The output signal for temperature sensors is PT100 resistances. All these signals are acquired by the Digital Multimeter through the multiplexer module.

Several approaches have been used for measuring liquid levels, some of them are: distance measurement based on pixel number variation in images of digital cameras [9], Non-contact liquid level measurement with electromagnetic–acoustic resonator sensors [10], continuous liquid level measurement technique based on a linear electrode array [11], multi-sensor system using plastic optical fibers [12], using capacitive sensors [13] and laser pointer with cameras [14].

At the moment it has not been possible to find any automatic level meter suitable for our system, because the liquid's dielectric constant changes during the process eliminating the capacitive sensors, or they are intrusive, being not possible to introduce any sensors inside the reservoir without to disturb the process, reservoirs should be heat isolated so that only one slot can be done,