Journal of Machine Construction and Maintenance
QUARTERLY 1/2019(112)
ISSN 1232-9312
p. 109–114

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CONTROL SYSTEM OF A TEST RIG FOR THE PRE-TREATMENT OF WATER USING DEPTH FILTERS

Key words: pre-treatment, depth filter, control system, PLC, HMI.

Abstract: The work presents the construction and the description of the operation of a test rig for the preliminary treatment of water and wastewater and testing the filtration and separation properties of non-woven depth filters. The stand was equipped with a control system for the initial filtration of water and wastewater as well as to investigate the filtration and separation properties of non-woven depth filters. The stand was adjusted to work in semi-real conditions for further use in industrial plants.

Automatyzacja stanowiska do badania procesu wstępnego oczyszczania wód przy użyciu filtrów wgłębnych

Słowa kluczowe: oczyszczanie wstępne, filtr wgłębny, system sterowania, PLC, HMI.

Streszczenie: W pracy przedstawiono budowę oraz opis działania instalacji do wstępnego oczyszczania wód i ścieków oraz badania właściwości filtracyjno-separacyjnych włókninowych filtrów wgłębnych. W ramach przeprowadzonych prac opracowano system pomiarowo-sterujący umożliwiający automatyzację procesu wstępnej filtracji wód i ścieków oraz badania właściwości filtracyjno-separacyjnych włókninowych filtrów wgłębnych. Zmodernizowane stanowisko poddano weryfikacji podczas jego pracy w warunkach semirzeczywistych. W ten sposób zautomatyzowana instalacja jest przygotowana do bezpośredniego wykorzystania na potrzeby przemysłowe.

Introduction

In recent years, there has been increasing interest in the possibilities of using filtration and separation techniques for the recovery of water from industrial wastewater [1–3]. The most often used technique involved pressure membrane processes preceded by pre-filtration with filters enabling deep, septic, sack filtration [3–5]. This configuration enables the rationalization of the management of water and wastewater in industrial enterprises by limiting water consumption and wastewater impact on the environment, eliminating substances particularly harmful to the environment from the waste stream, and using closed cycles and reuse of water [6, 7]. Rational water and wastewater management is a source of significant savings in industrial plants, and due to legislative standards announced by the EU and Polish authorities, it may become an obligatory element of economic activity [8–11]. The development of wastewater treatment and closed water cycles technology in industrial enterprises contributes to the intensification of research on the development of new filtration materials [12–14], which should be tested for their filtration and separation properties in semi-real conditions before being implemented into industrial practice. Filter systems currently available on the market, including depth filtration, are not well adapted to automatically control material properties and phenomena associated with filtration processes. The development of specialized and automated monitoring systems for phenomena occurring during filtration is an indispensable element for selecting appropriate strategies to counteract these phenomena, including organic and biological matter deposition, which effectively decrease filtration and separation efficiency [15]. The degree of automation of this type of systems is a key determinant of the innovation of filtration and separation systems. In addition, professional water treatment systems and wastewater treatment operating in a maintenance-free manner are the main interest of industrial recipients.

As a part of the work, a measurement and control system was developed that would enable the process to be carried out automatically on a pre-treatment bench and the filtration and separation properties of non-woven depth filters and its testing when working in semi-real conditions.

1. Filtration test rig

A measurement and control system was designed for the test rig that consists of the following elements: filter unit housing (e.g., non-woven depth filter), a feed pump controlled by the inverter, a feed tank with a controller of temperature, a valve system, and devices for measuring and controlling the flow, pressure, liquid volume, and its temperature. Fig. 1 shows the pre-filtration rig setup before it was equipped with a system for automation.

The test rig has been designed to work in three modes. They were presented in Fig. 3. In the main (closed) cycle, the liquid from the tank with a given capacity is pumped towards the test filter housing. The liquid flows through a housing towards the tank in a continuous mode. The second cycle (closed) enables the contact of the liquid with the filter only by flowing through the filter housing and bypass, and the filter with an additional exit in the base of the filter housing allows the liquid to be returned to the tank. In an open mode, the liquid from the tank is forced towards the filter housing. Depending on the research methodology, the filter can operate in standard conditions or flow tangential to its surface with continuous or closed-loop mode.

2. Control and measurement system

A control and measurement system has been developed that includes a PLC and a 5.8” HMI touch operator panel. The PLC and HMI panel [16] are provided with webservers, so that they can become part of the Intranet and be operated and possibly diagnosed or reprogrammed remotely. The PLC acting as a server or, e.g., a Modbus Server TCP can be incorporated into a test equipment network and monitored. A variety of PLC communication protocols facilitate extensions with other measurement devices. The pre-filtration stand in Fig. 2 features such a control and measurement system.

The control and measurement system consists of the following subsystems:

- Configuration of the stand valves,
- Measurement and stabilisation of temperature,
- Measurement and stabilisation of flow,
- Measurement of pressure,
- Safety devices,
- User communication, and
- Process registration.

a) b)

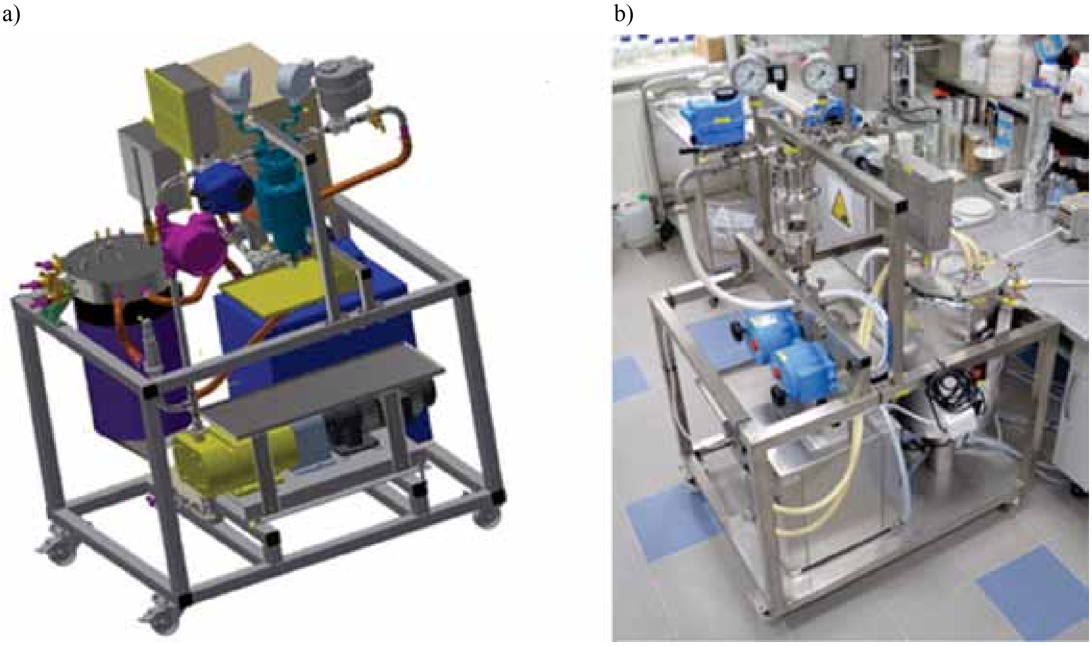


Fig. 1. Pre-filtration stand for testing filtration and separation properties of non-woven depth filters: (a) 3D scheme of the stand construction, (b) built prototype stand before automation

The subsystem for configuration of the stand valves comprises an appropriate arrangement of four three-way ball cocks including electric actuators. A valve position is signalled via contacts of its end switches. These valves are designated as Z1, Z2, Z3, and Z4 in the visualisation diagram (Fig. 3). The valves are automatically set from the operator panel to two modes:

1) Automatically: The appropriate configurations of the main (large) cycle, small cycle, and open cycle are selected automatically. Z1, Z2, Z3, and Z4 are set in succession to limit power supply. A wrong configuration cannot be set.
2) Manually: Each individual valve can be set separately; however, only one actuator can operate at any given time. It is possible to set a wrong configuration in this case.

Correct, unacceptable, and acceptable configurations are signalled with text messages and lights. When a configuration is correct, the process of heating and flow can be initiated.

The subsystem for measurement and stabilisation of temperature employs the following equipment:

- Temperature measurement is made at the inlet and outlet of a tested filter with heat insulated shroud sensors mounted on the pipe.
- Temperature measurement is made with a sensor clipped on a heat-insulated tank with the filtered liquid. The heaters have an in-built temperature limiter. Any temperature regulation other than on/off controlling needs not be applied owing to large time constants of the liquid heating system. Band heaters support the main tank temperature system

a) b)

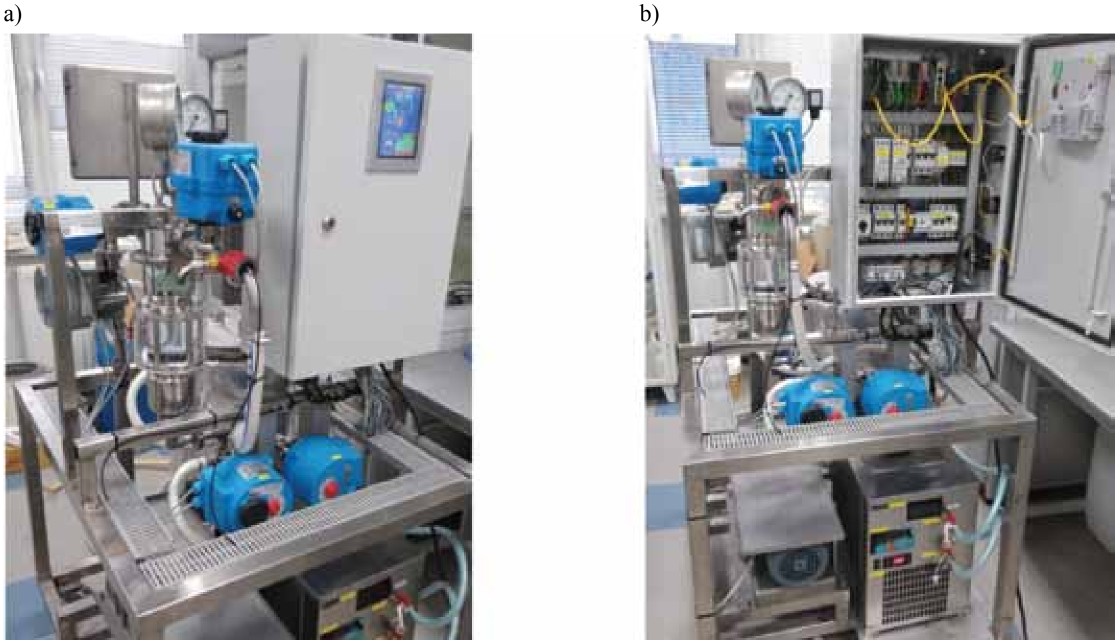


Fig. 2. Pre-filtration stand including a control and measurement system

a) b) c)

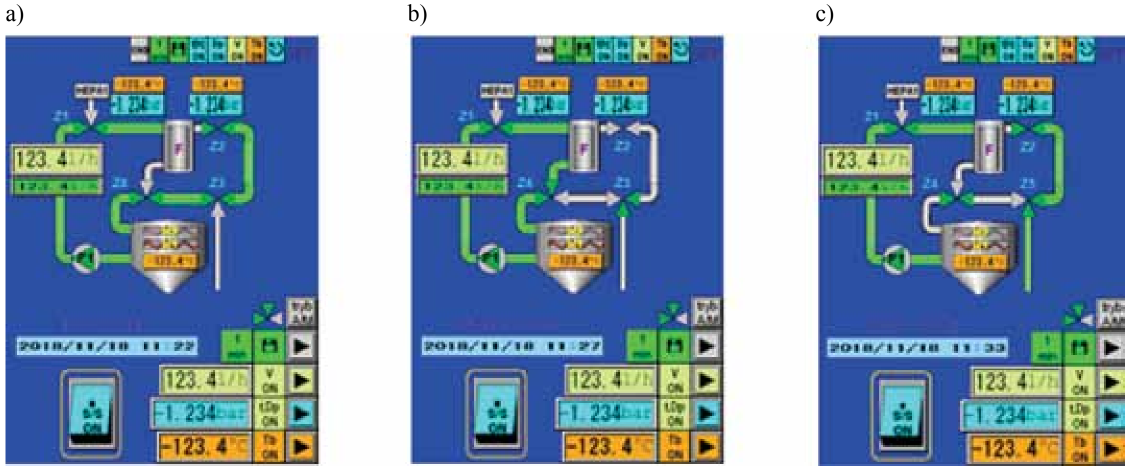


Fig. 3. The subsystem for configuration of the stand valves: (a) main (large) cycle status, (b) small cycle status, (c) open cycle status

by means of an autonomous circulator system. The circulator heats a tested liquid via a coil placed inside the tank.

Shroud or clip-on sensors with a grid-powered 4–20 mA converter are used. The sensor clipped on to the tank additionally restricts the temperature of the band heaters. Heat losses arise at pipe joints, which cannot be insulated due to performance considerations. The implemented fuzzy algorithm of temperature control, in spite of equipment limitations, helps to control temperature with an accuracy of ±1.5°C.

The subsystem for measurement and stabilisation of flow consists of a flow meter with a 4–20mA outlet and an actuator comprising a gear pump and a converter. A characteristic of the open system was determined as the control and measurement system was started. The following dependence was produced:

$$V\,[dm^3/h] = 19.5714 * f\,[Hz] - 189.05, \quad (R^2 = 0.9962)$$

where f [Hz] – the converter outlet frequency.

Control in the feedback system was executed using the converter settings and its inbuilt PID and by implementing an original flow stabilization algorithm in the PLC. The scan time of the flow regulator was selected experimentally as 3.2 seconds[1]. The accuracy of stabilisation is high, namely, ±1.5 dm^3/h, producing 0.25%FS.This accuracy is better than assumed initially.

The subsystem for pressure measurement consists of 4–20 mA analogue output clock sensors. The pressure sensors are in a classic arrangement –up and downstream of a tested filter.

The subsystem of safety devices encompasses equipment and software. The following events are signalled:

- Fuse alarms;
- Converter alarms – thermal overload relay of the motor, overload;
- Damage to analogue tracks – inbuilt diagnostics of input and output analogue module in the PLC;
- Significant (emergency) excess of the heater temperature – power is cut and the device is switched off;
- Excess pressure differential alarm up and downstream of a filter;
- Contactor malfunction – auxiliary contacts are used and original software is implemented to the PLC;
- Malfunction of valve Z1, Z2, Z3, and Z4 actuators, e.g., an error when the limiting switch status is incorrect and the resetting takes too long; and,
- Wrong configuration of valves Z1, Z2, Z3, and Z4.

A mechanism limiting values of parameter inputs was programmed. Breakdown information is signalled on all screens of the operator panel. The diagnostic screen on the operator panel indicates the causes of a breakdown and enables its cancelling following repair.

The subsystem of user communication is executed via the HMI operator panel and comprises the following:

1) Setting configurations of valves Z1, Z2, Z3, and Z4,
2) Setting the temperature of a tested liquid,
3) Setting the flow rate,
4) Switching the device on/off, and
5) Saving and cancelling a recorded process in the PLC memory.

All temperature, pressure, and flow displays are assumed to have the same colour ranges and appearances. The parameter display and setting fields have the same contours as the parameters controlled, while their areas are grey.

Text descriptions are restricted to a minimum and graphic symbols are used. Text messages are available in Polish, English, German, Russian, and Spanish. Switch statuses are designated as ON or OFF. All the quantities measured and controlled are denominated in SI physical units.

The subsystem of process registration helps to record the process as required by users. RAM PLC memory can hold 4000 records. With 1 record every minute, this adds to approx. 66 days of registration, recording every 5 minutes – ca. 333 days of registration. A record contains date, time, pressures, flow, and temperatures.

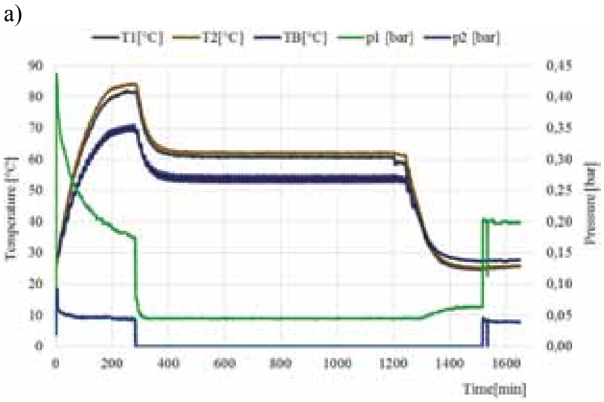
3. Verification testing of the control and measurement system

About 27 hours of testing was undertaken to verify the control and measurement system. Pressure, temperature, and flow measurements were recorded at 1-minute intervals. The verification test results (Fig. 4) show the temperature control has time constants that substantiate on/off PWM controlling. The flow is controlled with virtually no overshoots. Large time constants can be noted for Pressure p1 – upstream of the filter, and Pressure p2 changes promptly downstream of the filter and remains constant (free outflow).

The verification tests have demonstrated stable reading of temperature, pressure, and flow values both upstream and downstream of the filter. The parameters of temperature and the system flow are regulated at the time of the filtration process. The first process stage of the stand tempering enables sanitisation prior to testing. As the temperature grows, the viscosity of the liquid decreases and pressure at the filter inlet gradually reduces in effect. As the system's temperature lowers in the final phase, a minor pressure rise can be noted

[1] The scan time is the time of the programme module developing control. It provides for stable regulator operation

a)



b)

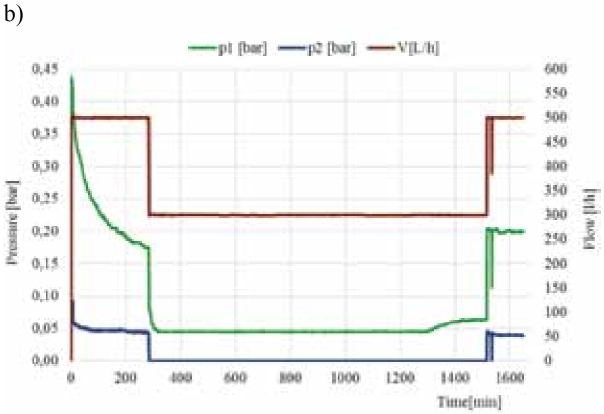


Fig. 4. The verification test results: a) the pressure and the temperature upstream (p1, T1), downstream (p2, T2) and the tank (TB), b) the pressure upstream and downstream (p1, p2) with the flow (V)

(Fig. 4a). The pressure variations at the filter inlet and outlet are also driven by changes of the liquid flow. As the flow is reduced, pressure at the filter inlet drops, then stabilises and remains steady until the flow is increased, causing the pressure to rise abruptly (Fig. 4b).

On the basis of the verification testing (Figs. 4 and 5), it was found that temperature control had an accuracy of ±1.5°C and flow control had an accuracy

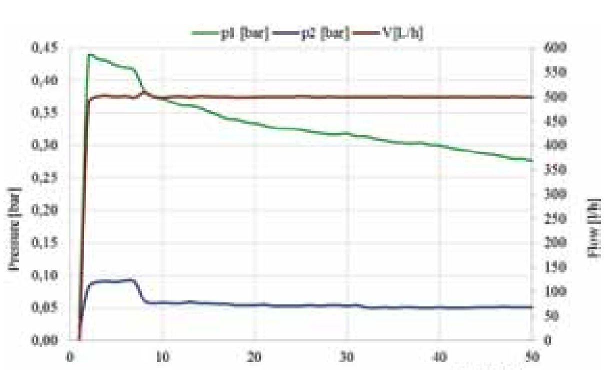


Fig. 5. Pressure upstream (p1) and downstream (p2) of the filter and the flow during the initial filtration process

of ±1.5 dm^3/h, which produces 0.25%FS. This means the developed control and measurement system allows for good stabilisation of temperature and flow and, as such, can be used in the process of water and sewage pre-treatment and the testing of filtration and separation properties of depth filters.

Conclusion

The filtration stand in this study for the preliminary water and wastewater treatment and determining the filtration and separation properties of non-woven depth filters was equipped with an automatic measurement and control system. The use of a modern PLC controller allowed the automation of the temperature and flow stabilization procedure, which are the key parameters for controlling the water pre-treatment process and testing the filtration and separation properties of depth filters. The adjusted stand can also be used in the study of phenomena accompanying the use of filtration materials.

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