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Experimental investigation of two-phase closed thermosyphon used in heavy duty extrusion pelleting line

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A B S T R A C T

Efficient cooling system is an essential part of heavy duty extrusion pelleting line which plays an important role in production engineering of megaton polyolefin. In this paper, a new cooling system based on two-phase closed thermosyphon (TPCT) used in heavy duty extrusion pelleting line was presented. Comparative experimental results show that thermal performance of TPCT is more efficient, and the temperature uniformity is much better than traditional extruder (similar to coiled heat exchanger) in preheating process and extrusion reaction process. The effects of different operation conditions: filling ratio (0.2, 0.35, 0.5, 0.65 and 0.8), flow rate of cooling water (120 L/h, 180 L/h, 240 L/h, 300 L/h and 360 L/h) and heating power (7 kW, 9 kW and 11 kW) on thermal characteristics were experimental investigated, respectively. The results show that temperature of barrel inner wall increased significantly as filling ratio increased and evaporator appeared dry out when filling ratio is 0.2. The flow rate of cooling water affected the condenser section obviously, but had little influence on evaporation section. With increase of heating power, the start-up time decreases and the heat transfer coefficient increased. An ideal cooling scheme was concluded: the liquid filling ratio was 0.35, the cooling water flow rate was 180 L/h and the heating power was 11 kW when working medium was water.

1. Introduction

With the increasing demand of polymer materials, plastic processing machinery has developed rapidly. Heavy duty extrusion pelleting line is the important equipment for post treatment of polyethylene or polypropylene plant. A wide variety of screw extruders have been sprang up in recent years, particularly large-scale twin-screw extruder [1]. Some researchers focused on the influence of operating conditions and screw geometry on the machine behavior. Syrjala [2] presented an approach to efficiently compute the three-dimensional fluid flow and heat transfer in the melt conveying section of a single-screw extruder. A procedure combining numerical and experimental techniques was developed by Mohamed et al. [3] to estimate the average heat transfer coefficient for twin screw extruders. The average heat transfer coefficients were expressed in terms of the Brinkman and Graetz numbers, with excellent statistical correlation. Teixeira et al. [4] developed a complete and precise calculation of flow and heat transfer along co-rotating twin screw extruders by taking advantage of the previous modeling efforts. To conclude, the vast majority of previous research are only focused on the effects of operating conditions and screw geometry. However, few studies have evaluated the disadvantages of traditional cooling pipe in terms of temperature uniformity. The heat generated from the reactive extrusion is particularly difficult to remove quickly due to the low heat transfer coefficient of viscous polymer. The current drilling type extruder utilizes the cooling water for heat removal but is often subject to limited porous heat transfer area and low efficiency. It will not only cause equipment failure, but also lead to product impurity under unevenly distributed temperature. Nowadays, the heavy duty extruder suffered from low efficiency which compromise its economics performance. It is necessary to develop an efficient cooling system for heavy duty extruder.

A heat pipe is a two-phase heat transfer device with a high effective heat transfer rate through evaporating and condensing a fluid that is circulating in a sealed container [5]. It possesses many advantages, such as small temperature difference, compactness, high heat transfer efficiency, single direction heat transfer (thermal diode), lower costs, light weight [6]. It has been playing a very important role in many industrial sectors, especially in improving the thermal performance of heat exchangers as an effective heat removal method [7].The heat pipes can be classified as three types: a conventional heat pipe (CHP), a two-phase closed thermosyphon (TPCT) and an oscillating heat pipe (OTP) [8]. TPCTs are essentially heat pipes, but without the wick structure. TPCT

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constituted of three sections: evaporator at the bottom end, condenser at the top end, and adiabatic section in the middle [9]. The difference between a CHP and a TPCT is that the TPCT uses gravity to transfer the heat from a heat source that is located below the cold sink.

Many researchers have focused on heat pipe with the aim of improving the heat exchange performance in different occasions widely. An experimental investigation of the effect of filling ratio on the steady-state heat transfer performance of a vertical TPCT was performed by Jiao et al. [10], working fluid were two different geometries of the TPCT with nitrogen. They proposed the range of filling ratio which can keep a TPCT steady and effective based on analysis and comparison. Amatachaya et al. [11] investigated the effects of cross-sectional geometries, filling ratio and aspect ratio on thermal performance of thermosyphon at different rates of heat input. The results indicated that the flat two-phase closed thermosyphon had a higher average wall temperature in the evaporator section than that of the conventional two-phase closed thermosyphon. Cao et al. [7] developed a controllable separate heat pipe (CSHP) and achieved an active control method. They presented conducted a series of experiments to analyze the start–stop and heat transfer performances of CSHP at various R134a fill ratios and heat sink temperatures. Their experiments results showed that CSHP start up quickly in approximately 15 s and the quickest stopping time of CSHP approximate to 80 s. Solomon et al. [12] studied the heat transfer augmentation of a TPCT with a thin, porous copper coating and compared it with an uncoated TPCT. They explored the effects of the inclination angle, power input and thin copper coating on the performance of the TPCTs. The heat transfer coefficient of the evaporator is found to be enhanced up to 44% at a heat flux of 10 W/m^2 for an inclination angle of 45°. A high temperature special-shaped heat pipe coupling the flat plate heat pipe and cylindrical heat pipes (HTSSHP) were fabricated and tested by Wang et al. [13], they experimentally analyzed the start-up characteristics, isothermal performance and thermal resistance variation of HTSSHP. Their work was helpful to establish the preliminary understanding of the operating characteristics on HTSSHP and provided some suggestions for its normal operation and structure optimization. Hu et al. [14] studied wickless heat pipe photovoltaic/thermal (PV/T) system and wire-meshed heat pipe PV/T system working on different inclination angles by experiments. It was calculated that the thermal efficiency of the wickless heat pipe PV/T system and wire-meshed heat pipe PV/T system at zero reduced temperature was 52.8% and 51.5%, respectively.

To get over the problems of poor reliability and uneven temperature distribution, a new twin-screw extruder with TPCT was proposed. The objective is to verify new cooling system has a better temperature uniformity and thermal performance compared with traditional extruder. The effects of filling ratio, cooling water flow rate, and heating power on thermal performance of extruder with TPCT were experimentally investigated, respectively. A feasible operation scheme for high efficiency heat transfer is proposed for heavy duty polyethylene mixing and granulation machine with 300 kt/a output of in the actual production.

2. Experiment

2.1. Experimental apparatus

An experimental apparatus is built to carry out a thermal performance investigation on TPCT applied to extruder. The experimental apparatus used in the study is shown in Fig. 1 (a) and (b). It consists of an evaporator section and a condenser section. Evaporator section is the cavity between the barrel inner wall and the outer wall. It is heated by internal heater with a maximum power output of 11 kW at 380 V. Internal heater is put at the position of the inner wall like ∞ profile. The condenser section is condenser tubes in the upper part of the barrel, which cooled by cooling water. Fig. 2 (a) presents the three-dimensional structure of the extruder with TPCT.

The condenser pipe is designed as shell-and-tube heat exchanger, the working medium in the pipe layer is steam that temperature is between 180 °C to 260 °C, the working medium in the shell layer is cooling water that inlet temperature and outlet temperature are 25 °C and 80 °C, respectively. The outer diameter of the designed condenser pipe is 16 mm, thickness is 2 mm, total of 25 pipes are arranged in a square. There are six square fins with length of side 130 mm and thickness 0.5 mm on condenser pipes, the spacing of each fin is 4 mm. Comparative experiments of extruder with TPCT and traditional extruder were carried out using the same experimental system. Concrete structure diagram of traditional extruder are shown in Fig. 1 (b) and Fig. 2 (b).

2.2. Experimental system

A quite complete experimental system consists of seven modules: heating module, cooling module, temperature control module, measurement and data acquisition module, vacuum pumping module and filling module. Fig. 3 shows schematic diagram of the experimental system. The heating module is divided into two parts, internal heater and external heater. The external heater is a plate heater with heating power of 1.8 kW for preheating. And internal heater consists of 18 heating rods embedded in a copper block adhered to the inner wall. The condensing module includes a machine barrel, a pipeline pump, a water tank, a flow meter, a ball valve, and a heater used for heating the cooling water. The temperature control module is designed to control the temperature of internal and external heater and adjust the heating power. The measurement and data acquisition module is used for measuring experimental data such as temperature, cooling water flow and pressure. The temperature data acquisition system consists of T-type thermocouple, a data acquisition card and a data display and recording system. A vacuum pumping module and a working fluid filling module are also equipped.

As shown in Fig. 1, The temperature distribution along the extruder barrel inner wall is monitored using five thermocouples labeled T1–T5. These thermocouples are inserted into the small holes in the barrel inner wall. Thermocouple labeled T6 put at blind tube is used to monitor the saturation temperature of working medium. Two additional thermocouples labeled T7 and T8 are used to monitor the input and the output water temperatures from the condenser chamber. These two thermocouples are positioned at the center of the flow using two compression fittings. Thermocouples labeled T9 at outer surface of condenser pipe is used to monitor the temperature of condenser section. All of the thermocouples are read and monitored using a 16-channel Data Scan system, which is connected to a dedicated PC for an online data recording. And the OMEGA-CL355 type dry block calibrator is used to calibrate thermocouples.

2.3. Experimental procedure

At the start of each experiment, pipeline leak detection should be carried out firstly. Adjust the temperature control device and heating device, inject working medium into the barrel and connect thermocouples, fill the heat conductive grease in the small hole to reduce the measuring error, and record the initial temperature after opening temperature control device and data collector, record the barrel temperature when the copper block is heated to 60 °C, 100 °C, 140 °C, 180 °C and 250 °C to ensure temperature control and data collector display the barrel temperature correctly. Then use a vacuum pump for 20 min and measure leakage rate of the barrel in a certain period and fix the working medium to the desired value. Open the internal heater heating barrel to achieve the working conditions of continuous generation of shear heat in the actual reactive extrusion process. After that, open the circulating pump and adjust the flow rate of cooling water to appropriate value. The temperature of barrel inner wall and working medium, cooling water flow rate, inlet and outlet cooling water