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Research Paper

Subatmospheric boiling study of the operation of a horizontal thermosyphon reboiler loop: Instability

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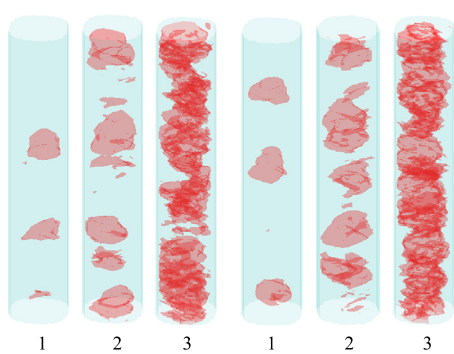
HIGHLIGHTS

- Characteristics of geysering instability in a horizontal thermosyphon reboiler loop is highlighted using Wire Mesh Sensor.
- Interconnection between geysering instability and accompanying churn flow is identified.
- Effects of stability parameters and pressure drop feedbacks on the loop at low heat fluxes are described.

GRAPHICAL ABSTRACT

The highlight of the characteristics of the geysering instability from analysed WMS data. Pictorial view of geysering instability, heat flux 9 kW/m^2 (P_S = 1.14 bar(a)), Static head = 1.265 m, valve setting = 1.0, process side pressure = 0.5 bar(a).



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ABSTRACT

Distillation and chemical processing under vacuum is of immense interest to petroleum and chemical industries due to lower energy costs and improved safety. To tap into these benefits, energy efficient reboilers with lower maintenance costs are required. Here, a horizontal thermosyphon reboiler is investigated at subatmospheric pressures and low heat fluxes. This paper presents detailed experimental data obtained using Wire Mesh Sensor in a gas-liquid flow with heat transfer as well as temperatures, pressures and recirculation rates around the loop. Flow regimes which have been previously identified in other systems were detected. The nature of the instability which underpins the mechanisms involved and conditions aiding instability are reported. Churn flow pattern is persistently detected during instability. The nature of the instability and existence of oscillatory churn flow are interconnected.

1. Introduction

Distillation is still one of the major units for separations in the chemicals and oil refining industries. It is also one of the largest users of energy. It is only in providing more efficient equipment in this area that energy savings will be made. It must be remembered that a distillation column consists not only of the column itself but also of the associated reboiler and condenser, the providers of vapour and liquid to the column. Improved design of these associated units will yield energy savings. One way to achieve improvements is by better understanding of their operation. A majority of the reboiler operate as thermosyphons, liquid is driven

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through the heat exchanger via a density difference created by heat input to the system. At the outlet of the exchanger there is usually a two-phase gas-liquid mixture with a lower density than the liquid descending from the distillation column. This density difference drives the flow. Thermosyphon reboilers have lower operating and maintenance costs than other reboiler types due to their simplicity and the absence of a mechanical pump. They are characterized by high heat transfer rates and low fouling tendencies, can be operated over a range of pressures and have proven to be adequate for heavy heat duties in petroleum and nuclear industries. Thermosyphon reboiler usage is fundamentally attractive because of the high heat fluxes. This imply a smaller heat transfer area and hence capital expenditure and also lower process liquid inventory compared to other reboilers as reported by Japikse et al. [13]. Also horizontal thermosyphon reboilers have been judged, through research, to be superior in thermal performance to vertical thermosyphon and kettle reboilers [17]. This is due to their higher circulation, local boiling temperature differences and heat transfer rates. Notwithstanding the merits, the presence of two-phase flow initiates complications. Researchers and designers have to consider many aspects including pressure drop, flow regime prediction, realistic boiling curves, and flow instabilities [14].

Horizontal thermosyphon reboilers are much more effective at low temperature differences than kettle and vertical thermosyphon units. Vertical thermosyphons are also less attractive than horizontal type when heat transfer area requirements are large due to mechanical considerations (e.g. distillation column height). Fluids with moderate viscosity boil better in horizontal thermosyphon than in vertical units. It is possible to use low-finned and enhanced boiling tubes on the shell side of horizontal thermosyphon reboilers. The vertical height of the riser between the horizontal thermosyphon and the column discharge nozzle allows for very flexible hydraulic design. The static head requirements are lower for horizontal thermosyphon reboilers than for vertical units. And because of their high circulation rates, the temperature rise for boiling fluid across horizontal thermosyphon reboilers is lower than that for kettle reboilers. Yilmaz [17] reports that this leads to higher local boiling temperature differences and higher heat transfer rates for horizontal thermosyphon. Their size is not limited with respect to length of tubes and weight; thus the requirements for high surface area are in their favour. They handle the process fluid on the shell side; a scheme which many applications favour, particularly where the heating fluid has fouling tendency. They also offer easier access for mechanical cleaning of tubes by pulling the bundle as noted by Collins [7].

In industry, the advantages of operating such equipment under vacuum, such as in low pressure distillation include: higher thermodynamic efficiency; reduced energy consumption; processing of heat sensitive materials at low temperature and achieving better separation. The low temperatures will allow cheaper materials of construction to be used [6]. Nowadays, many applications in distillation are looking to use subatmospheric pressure operation to lower energy costs and improve safety [3]. Distillation under vacuum is also a commonly desired process in the chemical industry for extraction of essential oils, deodorisation of vegetable oils and purification and drying of chemicals. This is because there are favourable advantages over atmospheric pressure distillation which include: (1) use of lower process temperatures as a result of reduction in boiling points and hence shorter time of thermal exposure of the distillate so that thermally sensitive substances, like vitamin and hormones, can be processed easily, (2) reduction of energy consumption as a result of lowered boiling point, (3) increase in relative volatility of materials resulting in higher production rates, (4) change in position of the azeotropic point enables separation of hard-to-separate materials, (5) reduction of oxidation losses of the feed stock, and (6) reduction in stripping steam requirements for de-odourisation process of oil due to increased specific volumes (of steam), enhanced agitation and stirring of the oil. However, vacuum operation makes the thermosyphon system more susceptible to instabilities due to lowered system pressure and this initiates oscillatory flow. The improved vaporization rate results in high vapour mass flux, which was noted by Benson et al. [6], makes the subatmospheric pressure boiling systems prone to instability. These instabilities are magnified by decreasing: system pressure; mass flow rate; inlet resistance and inlet subcooling and by increasing: riser height [10]. Of all the few articles published on thermosyphon under vacuum, none is centred on horizontal thermosyphon reboiler. This paper presents experimental data conducted on a horizontal thermosyphon reboiler loop at low heat fluxes and using Wire Mesh Sensor reports the nature of the instability and existence of interconnected oscillatory churn flow.

2. Experimental arrangements

2.1. Flow facility

The present work was carried out in an upgraded version of the facility employed by Hills et al. [12] and Azzopardi and De Leon [5] with detailed description presented by Agunlejika [1] and Agunlejika et al. [2]. It is shown schematically in Fig. 1. The essential features are: the reboiler (a horizontal shell and tube heat exchanger with 16 "U" tubes heated by steam condensing on their inside, the steam was provided by the laboratory steam main), a riser, a vertical column and a pair of condensers in series. The riser and column are made of borosilicate glass (possibly from QVF) to permit observation of the flow.

Valve, V8, is placed in the recycle line to provide an inlet flow restriction to enhance stability. A gate valve has been selected for this purpose rather than a globe valve so as to give a smaller restriction when fully open. The facility is instrumented with an electromagnetic flow meter in the recycle line to monitor the recirculation rate, five absolute pressure transducers (P0-P4) and twelve T-type Ni-Cr thermocouples (T0-T11) with positions as indicted in Fig. 1.

The continuous output of all of these is monitored at 100 Hz by a data logger connected to PC which also stores the data. In addition, the flow rate of the condensed heating steam and the condensed process fluid are measured over a timed interval. The accuracy of the measurements have been assessed to be: pressure, ±2%; temperature ±1%; recirculation rate ±4%. Apart from the upgrade in instrumentation relative to that employed by Hills et al. [12] and Azzopardi and De Leon [5] the other major change in the facility for its use in the present work is the provision of valves and connections which enable vacuum to be applied to the process side.

2.2. Wire Mesh Sensor

The Wire-Mesh Sensor (WMS) is a high speed imaging technique which can be used to quantify the location of the phases with high spatial and temporal resolution of the flow based on the relative permitivity measurements made at the wire crossing points. The principle is based on a matrix-like arrangement of the measuring points whereby the wire mesh subdivides the flow channel cross-section into a number of independent sub regions, where each crossing point represents one region as in Fig. 2(b). Two arrays of wires; transmitters and receivers, are stretched along chords of a cross-section with a small axial separation, 1.5 mm, between them and the arrays are orthogonal to each