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INVESTIGATION OF FLOODING, RE-ENTRAINMENT AND GRADE EFFICIENCY IN AXIAL FLOW CYCLONES

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Slotted wall axial flow cyclones with a conventional center-body swirler are found to exhibit significant flooding at low air velocities. This was observed to be due to significant liquid hold-up on the vanes which eliminated the swirl and led to a pulsating frothing behaviour. At higher velocities, the liquid dispersed and separated through the wall slots. The onset of entrainment of liquid was determined visually. In the low velocity frothing region liquid was entrained directly but coalesced and fell back down the vortex finder. At higher gas velocities entrainment occurred due to several mechanisms.

Design changes were introduced to improve performance. The center body was replaced by a new design of vane swirler around the periphery of the tube inlet. This significantly increased the swirl in the tube. Adapting four of the vanes to operate as liquid drainage channels eliminated the flooding phenomenon observed at low gas velocity and enabled the tube slot area to be reduced. This, combined with a larger diameter vortex finder, significantly increased the fraction of flow through the vortex finder, with no extra overall pressure drop. Liquid entrainment in the new design was reduced by positioning liquid slots at the top of the tube and by the use of a skirt.

Grade efficiency was determined for the improved cyclone design operating over a range of gas flowrates. The cut size for outflow to the vortex finder was found to vary from about 7 μm at an air velocity of 4.5 ms^{-1} to about 4.5 μm at 11 ms^{-1}.

Keywords: axial flow cyclone; flooding; re-entrainment; pressure drop; grade efficiency.

INTRODUCTION

The removal of fine liquid droplets from a gas stream, or demisting, is an important stage in oil–gas separation. Ideally, demisting equipment should be compact, able to exhibit high gas handling capacity with low pressure loss as well as having a low maintenance requirement. It is also beneficial if the equipment can handle a broad range of liquid to gas ratios and have a tolerance to changes in inlet droplet size distribution and flow rate. Such characteristics suggest the application of an axial flow design of cyclone. A recent development in axial flow cyclones has been the incorporation of drainage slots into the barrel walls to allow immediate drainage of collected films and the avoidance of re-entrainment of the collected liquids. This type of cyclone is of considerable interest to the oil and gas industry and is the subject of this work.

Cyclones have been a popular and valuable tool in the separation industries for more than a century because there are no moving parts that can wear out or break. Consisting of a cylindrical body, an inlet and exit port, a cyclone separator is fairly simple, inexpensive both to build and to maintain as well as being safe in operation. Most research and industrial applications to date have focused on reverse flow cyclones (Shepherd and Lapple, 1939) for solid–gas separation (Alexander, 1949; Iozia and Leith, 1989; Stairmand, 1949; Hoffmann and Stein, 2002). There has been very little work carried out using cyclones, of whatever geometry, for gas–liquid separation and the application of axial flow cyclones for either liquid or solid separation is not well understood. Axial flow cyclones do, however, offer the prospect of small size per unit gas throughput. This paper presents an experimental study of the key potential operational limitations in axial flow cyclones, flooding and re-entrainment. Also important is the cyclone pressure drop and grade efficiency, for which data is also presented. The significance of the data is perhaps best considered in the context of a typical cyclone application, as detailed below.

TYPICAL CYCLONE APPLICATION

Knitted meshes are currently the primary gas demisting method employed in oil–gas production facilities,

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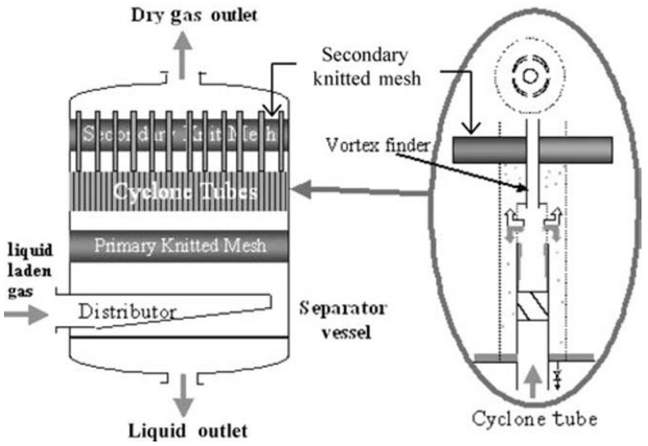

Figure 1. The overall demisting vessel.

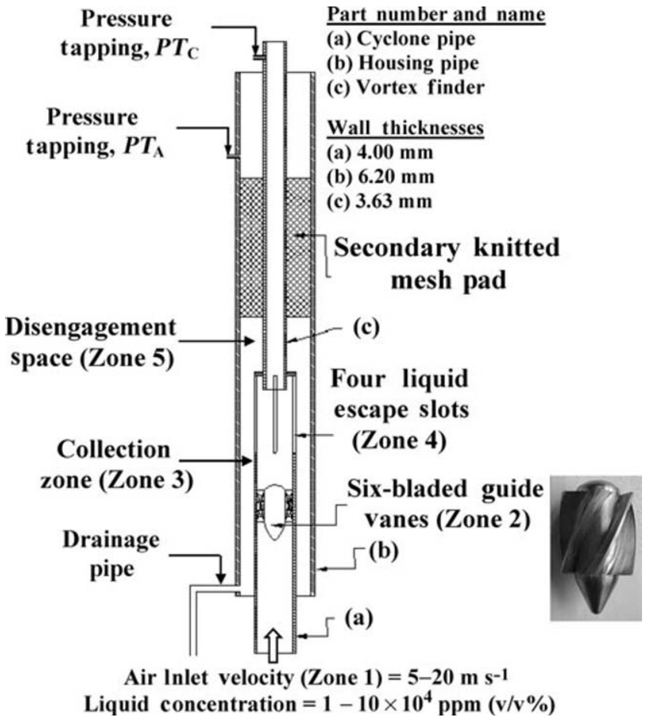

Figure 2. Initial tested geometry.

however, their use is limited to low superficial gas velocities and they have a tendency to flood under high loadings. To counteract these deficiencies, cyclones can be included in a hybrid system which should increase the turndown ratio whilst retaining the advantages of being cheap, reliable, easy to maintain and safe. As shown in Figure 1, a set of axial-flow cyclones is operated in parallel and in combination with primary and secondary meshes inside a large vessel. A primary layer of mesh is provided immediately following the gas inlet, which is intended to perform the required separation under conditions of low liquid or gas loading. At higher loading, this mesh can become inefficient or flooded and hence further downstream separation is provided by a combination of the cyclones and a secondary mesh layer. The cyclones act to extend the range of the secondary mesh. The clean gas flowing through the vortex finders by-passes the secondary mesh layer, reducing the velocity through it, and hence reducing its propensity to flood. Thus the flow split between vortex finder and mesh and their relative flow areas are important design parameters. The work reported here focuses on a single tube, representative of one unit in the bank of cyclones, with a target of about 70% of the supplied flow exiting through the vortex finder.

INITIAL CYCLONE DESIGN WITH CENTRE-BODY SWIRLER

The initial cyclone design used is detailed in Figure 2. It was adopted from the designs of Swanborn (1997) and Cuypers and Stanbridge (2000) which also had slots as a liquid drainage route, but in addition had a recirculating path in a hollow swirling centre body so that a small amount of the secondary gas flow was entrained back into the main flow to increase the efficiency. There are also some uniflow cyclone designs that use a number of vanes shaped helicoidally around a body without the recirculation zone (e.g., Oranje, 1990; Karlsson *et al.*, 1993).

The initial design of axial cyclone tested here was constructed from clear PVC with an inner diameter of 52 mm and a total height of 842 mm. The cyclone itself could be considered in five zones, as indicated in Figure 2. Zone 1 was the inlet region (175 mm from tube inlet to the vanes) where the air and water droplets were introduced. Zone 2 was the brass centre body with the swirling vanes. Six-bladed guide vanes at 30° between blade plane and the axial axis were attached to a centre body. The 30-mm diameter centre body had an aerodynamic hub at the front and a rounded end to aid swirl production and minimise pressure drop. Immediately downstream of the blades, the liquid droplets were thrown to the cyclone wall by centrifugal force. This was the collection stage, Zone 3. Zone 4 was the stripping section where slots were provided to allow the collected liquid to drain from the main cyclone tube. The slots were 5 mm wide and 111 mm long and started 53 mm downstream of the vanes. Having passed through the slots, the liquid entered Zone 5, a disengagement space. In practice, in a multiple bank of cyclones, there would be no outer casing and disengagement would occur in gaps between the cyclones, above the vessel's plenum plate to which the cyclone's inlets would be attached. The air and liquid streams in Zone 5 are referred to as secondary flows. The secondary gas flows through layers of the second knitted mesh pad, which acts as a secondary collection device. The details of the secondary mesh can be found in Table 1. Liquid droplets that flow with the air should be trapped here, coalesce and drop back to the bottom of the disengagement space to drain. Therefore, it is a design objective that only a small fraction, perhaps as low as 30%, of the total gas flow passes with the liquid to the disengagement space, so as to reduce the load on the secondary mesh and hence reduce its propensity to flood. Ideally, only clean gas will leave the system through either the top of the secondary mesh or through the cyclone exit pipe or 'vortex finder'. In the initial devise the vortex finder had an internal diameter of 26 mm.