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An ice-valve-based pressure-coring system for sampling natural hydrate-bearing sediments: Proof-of-concept laboratory studies

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ABSTRACT

Less than 60% hydrate-bearing sediment pressure cores can be retrieved by current pressure corers because of sealing failures. This is attributed to the sensitivity of mechanical valves to solid particles and drilling cuttings. In order to improve the pressurized core recovery of natural gas hydrate-bearing sediment coring, a pressure corer based on an ice valve made out of in situ drilling fluid during coring is proposed. A series of preliminary laboratory experiments were conducted to characterize the ice valves proposed for the pressure corer. The ice valves made from the pure drilling fluid (used in the Scientific Drilling Project of Gas Hydrate in the Qilian Mountains) or the drilling fluid contains different mass concentrations and granularity of quartz and kaolin particles. Several ice valves with various lengths were tested for their sustained pressure. Results show that the sustained pressure of the ice valve increases almost linearly with the valve length. An ice valve formed at −30 °C with a nominal diameter of 58 mm and a length of 85 mm can retain a pressure greater than 25 MPa without leakage. The sustained pressure of the ice valve can be adjusted by changing the ice valve length to accommodate different drilling sites. Experiments verified that the ice valves were insensitive to both solid particles and rust. It indicates that the proposed ice-valve-based pressure corer can be a potential solution to increase the recovery of pressurized hydrate-bearing sediment core.

1. Introduction

Natural gas hydrates in submarine and permafrost formations have been considered as an important potential unconventional energy resource, and can be relevant to global warming and drilling safety (Kvenvolden, 1993; Sloan and Koh, 2008; Janes et al., 2013; Hovland and Gudmestad, 2013). In-situ pressure core samples of hydrate-bearing sediments are important in geotechnical, geochemical, geological, and microbiological testing and analyses (Paull et al., 2005; Stern et al., 2011; Kneafsey et al., 2011; Lu et al., 2011a; Winters et al., 2011). The physical properties will experience significantly change because of gas hydrate dissociation and gas exsolution if the cores are retrieved without pressure (Paull and Ussier, 2001; Kumar, 2004; Paull et al., 2005; Sloan and Koh, 2008; Waite et al., 2008; Winters et al., 2011; Dai and Santamarina, 2014). It was found that often in excess of 95% (in some cases, at least 99.8%) of hydrocarbons are lost within 20–30 min of using conventional non-pressure coring at depth and gas sampling on the surface (Paull et al., 2000; Paull and Ussier, 2001). A degassing experiment on pressure cores is the only method that can accurately quantify the concentration of gas hydrates in cores (Dickens et al., 2000; Paull and Ussier, 2001; Abegg et al., 2008; Collett et al., 2013) and directly observe the morphological structure of gas hydrate within a sediment column (Jeffrey et al., 2009; Dai et al., 2012; Angus et al., 2013; Babu et al., 2013). Gas hydrate-bearing sediment samples retrieved and analyzed at full in-situ pressures are the “gold standard” for calibrating and establishing the physical and chemical analyses of non-pressure cores, and interpreting geophysical data (Schultheiss et al., 2008). Therefore, the pressure-coring technique for gas hydrate-bearing sediments has been deployed primarily in modern gas hydrate investigations.

Substantial efforts have been made to develop and improve pressure-coring techniques for gas hydrate investigations. These efforts have achieved the successful applications of two types of pressure corers: one type is based on the use of a ball valve mechanism to close and seal the pressure chamber where the core is contained on recovery, and the other type employs a flapper valve mechanism, as shown in Fig. 1. From 1973 to 1975 the Deep

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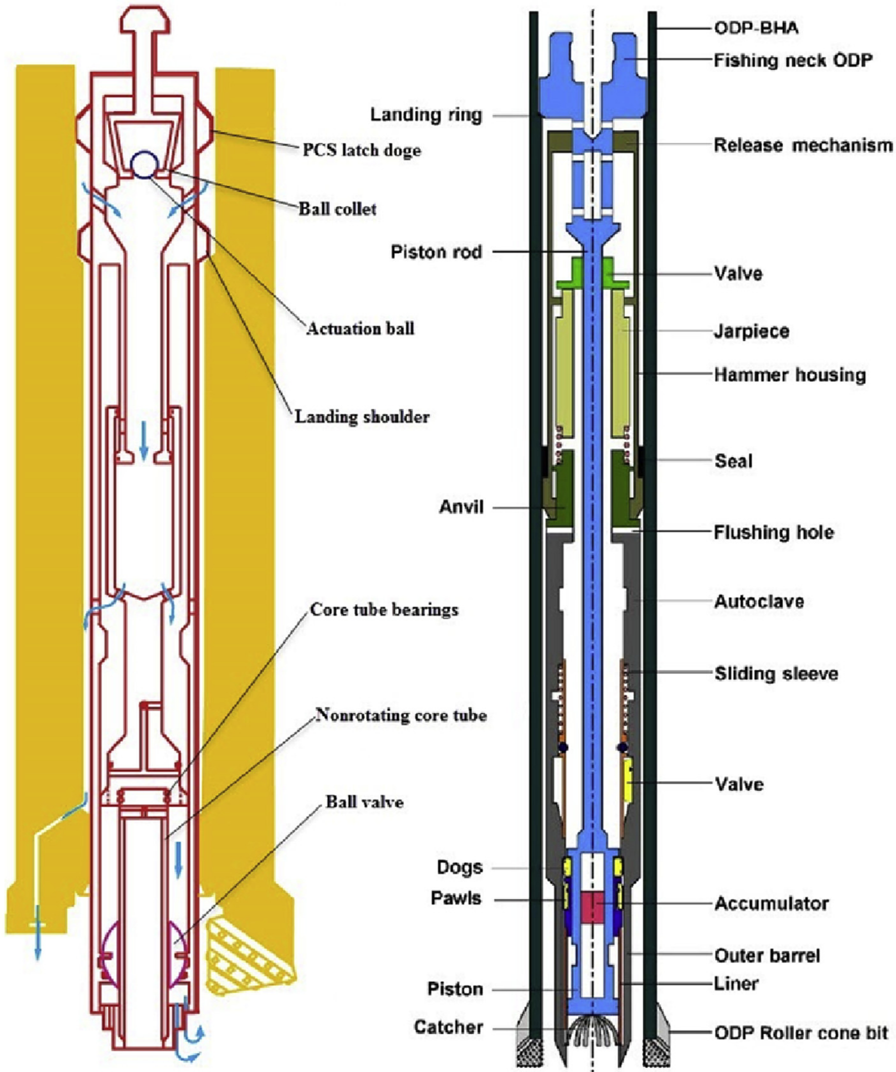

Fig. 1. Schematic of the two types of mechanical valve based pressure corer, PCS is based on the ball valve (the left one) and FPC is based on the flapper valve (the right one).

Sea Drilling Project developed the first wireline pressure core barrel (PCB I) prototype. In the succeeding five years, three generations of PCB were developed. The final version of PCB III was tested successfully during Leg 76 and was deployed three times in Leg 84, and this version had the first successful measurement of in-situ gas volume (Peterson, 1984). The wireline pressure core sampler (PCS) was developed by ODP to replace PCB III because the latter was incompatible with new bottom-hole assemblies (Pettigrew, 1992; Paull and Ussier, 2001). PCS has been successfully used to study in-situ gases and methane hydrate-bearing sediments during ODP Leg 164, 201, and 204, as well as on IODP expedition 311 and NGHP-01 (Matsumoto et al., 1996; Shipboard Scientific Party, 2002a; Dickens et al., 2003; Tréhu et al., 2006; Riedel et al., 2006; Collett et al., 2013). Two types of wireline pressure-coring systems were also developed in the EU-funded HYACE/HYACINTH programs: Fugro pressure corer (FPC) and HYACE rotary corer (HRC). FPC was developed to pressurize core samples in soft to stiff clays or sandy to gravelly materials, whereas HRC was primarily designed in sampling lithified sediments or rocks. These HYACINTH pressure-coring systems were successfully used on ODP Leg 204 and IODP expedition 311 and have been deployed in the Gulf of Mexico JIP Leg I, Malaysia Gumusut-Kakap Project, India NGHP Expedition 01, China GMGS Expedition 01, and Republic of Korea UBGH Expedition 01 and 02 (Hippe et al., 2006; Schultheiss et al., 2006; Collett et al., 2006; Zhang et al., 2007; Schultheiss et al., 2009; Matsumoto et al., 2011; Collett et al., 2013; Ryu et al., 2013; Bahk et al., 2013). Both the pressure temperature core sampler (PTCS) and its improved core sampler (i. e., Hybrid PCS) were developed by Japan and deployed in the Nankai Trough (Zhang et al., 2007; Matsumoto et al., 2011; Kubo et al., 2014). These pressure corers trap pressurized core samples inside a sample autoclave by using a hydraulically actuated ball valve or flapper valve. However, the ball valve or flapper valve is suffered from the infiltration of detritus, and metal seats and seals corrosion or blockage. The average pressure core recovery are relatively low not even to mention its complexity and the high costs of deployment. Some of the application cases is listed in Table 1.

The use of ice valves, also known as the pipe freezing technique, has been widely used, and its typical operation include changing valves or fittings, extending or blocking pipeworks, and testing pressure (Bowen et al., 1996; Keary and Bowen, 1999; Park and Son, 2002; Richardson et al., 2003; Chris, 2008; Gui and Liu, 2004; Stone et al., 2004). Pipe diameters with 813 mm were frozen (Bowen et al., 1996); the sustained pressures within 1300 bars (132 MPa)