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Development of Analysis and Transfer System of Seafloor Natural Gas Hydrate Pressure Core

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ABSTRACT

An analysis and transfer system(ATS), which can subsample cores and subsequently transfer subsamples into specialized chambers before they are sent to the laboratory for further measurements, is able to keep the in-situ temperature (2~4℃) and pressure (30MPa) during the transfer process, which can prevent the changing of physicochemical properties of the cores. The system has been tested in the South China Sea twice and shows an excellent performance on pressure maintenance, the amplitude of the pressure fluctuation caused by the movement of catcher and cutting unit is less than 20%.

KEY WORDS: natural gas hydrate; gravity-piston pressure corer; analysis and transfer system; pressure-retained; long-columnar core

INTRODUCTION

Natural gas hydrate (NGH) is a kind of ice-like solid compound composed of gas (mainly methane) and water, which can be formed in nature and man-made environment under low temperature and high pressure (Makogon, et al., 2007). Hydrate in the crust is a potential unconventional natural gas resource with abundant deposits, mainly distributed in the continental permafrost sedimentary layer, the ocean bottom at the outer edge of the continent and the deep seabed plain sedimentary layer. The gas content of natural gas hydrate is quite high; the unit volume of natural gas hydrate contains up to 180 times the volume of gas. The natural gas hydrate coring from the seafloor provides samples for the laboratory studying on physicochemical properties of natural gas hydrate and the condition of mineral reserves, which are of great importance for the development of the mining of the seabed resource, as well as the environmental protection.

Development of the pressure corer has involved teams around the world, including the International Ocean Drilling Program (IODP), the International Deep-sea Drilling Program (DSDP) and the European Union's Marine Science and Technology Program. The type and service conditions of major pressure-retained corers in use are shown in Table 1. However, it is still difficult to gain a single columnar pressure-retained core with a length greater than 3 m. As for China, the long gravity-piston pressure-retained corer developed by Zhejiang university (shown in Fig. 2) was tested on the HY6-11-03 voyage and obtained a single column of pressure-retained core of 14.15 m, which is the longest single column core with in situ pressure in the world so far.
Physical characteristics of NGH include shear strength, compressibility, porosity, permeability, thermal conductivity, pressure and temperature. Some features can only be measured in the laboratory. Therefore, the system which can subsample cores and subsequently transfer subsamples into specialized chambers for further measurements is the major objectives of researchers (Zhao, J., et al., 2011; 2012). PCATS, the Pressure Core Analysis and Transfer System shown in Fig.1, is the interface between the pressure corer and investigators using pressure

Table 1. Current service conditions of major pressure-retained corers

	Technical Parameters	Pressure-retained Methods	Temperature-retained Methods	Post Treatment	Coring History
DSDP-PCB	Max. 6 m coring length; 57.8 mm coring diameter; Max. pressure ≤ 35 MPa	ball valve; high pressure nitrogen	not active	pressure/ temperature	DSDP 42/62/76
ODP-PCS	Max. 0.86 m coring length; 42 mm coring diameter; Max. pressure ≤ 70 MPa	ball valve/ accumulator	not active	no	ODP 124/139/141/ 146/196
HYACINTH-FPC	Max. 1 m coring length; 58 mm coring diameter; Max. pressure ≤ 25 MPa; non-lithological sediment	a piston seal and a flap seal/accumulator	not active	V-MSCL	ODP 194/201/204 IODP 311 India-HGHP-1 China-GMGS-1 Korea-UBGH1
HYACINTH-HRC	Max. 1m coring length; 50 mm coring diameter; Max. pressure ≤ 25 MPa; non-lithological sediment	the piston seal and a flap seal/accumulator	not active	V-MSCL	ODP 194/201/204 IODP 311 India-HGHP-1
Japan-PTCS	Max. 3 m coring length; 66 mm coring diameter; Max. pressure ≤ 30 MPa	ball valve	adiabatic and thermoelectric coring liners	pressure/ temperature	Mackenzie Delta/ Kashiwazaki field and "Nankai Trough" well

Note: V-MSCL = A vertical multi-scanning device including magnetic susceptibility, conductivity, P-wave velocity and gamma ray (by GEOTEK Ltd., Northants, UK).

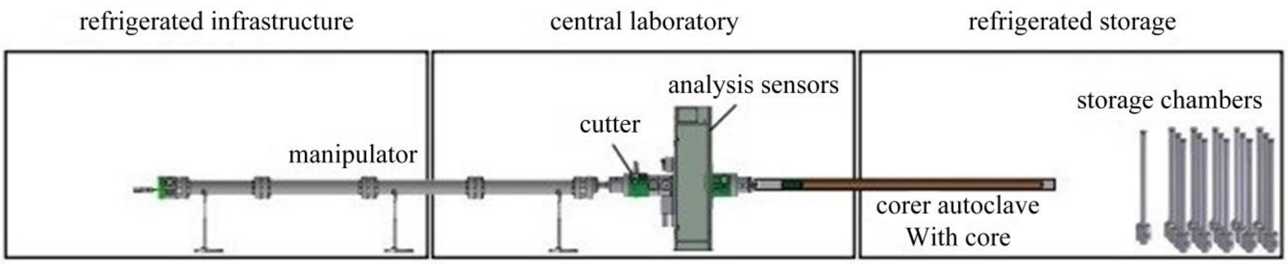

Fig. 1 Scale diagram of PCATS

core samples (Schultheiss, P, et al., 2006; 2009; 2011). Pressure cores can be transferred from compatible pressure corer into a specialized chamber (Santamarina, J. C, et al., 2012). Nondestructive analysis includes gamma density measurements, P-wave velocity measurements, and both linear X-ray images and 3-D X-ray computed tomography, providing data that has intrinsic scientific utility and is critical for the selection of subsamples (Chen, J. W, et al., 2013).

This paper is organized as follows: first, it presents a long gravity-piston pressure-retained corer and an analysis and transfer system of seafloor natural gas hydrate pressure core, including structure and technical parameters. Then, the working principles of the corer and transfer system are illustrated in detail. Finally, the sea trial of the system in the south China Sea (SCS) is introduced.

GRAVITY-PISTON PRESSURE-RETAINED CORER

As shown in Fig. 2, a long gravity-piston pressure-retained corer consists of sampling device, lifting and releasing device, flow guiding device and other accessories. The sampling device is composed of a pilot frame, a cutter, a piston, a catcher, core barrels, barrel joints and core liners, all of which are designed to penetrate sediments and obtain a columnar core. Core barrels included 6 plexiglass tubes with outer diameter of 100mm, wall thickness of 5mm, and length of 4.75 m. The lifting and releasing device is mainly composed of a lever, a counterweight, counterweight wire, a releasing hook, a releasing wire, and the hook is designed to release the counterweight when the corer comes close to the seafloor. The flow guiding device is designed to reduce the fluid resistance when the corer falls at high speed. The corer has a maximum capacity of 160 liters, a maximum sampling depth of 30 meters, and a maximum working depth of 3,000 meters. The pressure of the sample is maintained by the pressure compensator, and the sample is kept warm by the thermal insulation coating.

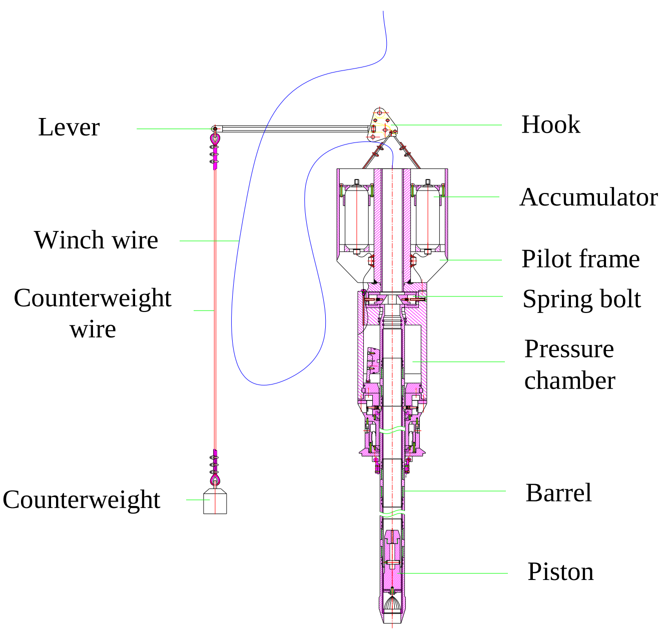

Fig. 2 The long gravity-piston pressure-retained corer

ANALYSIS AND TRANSFER SYSTEM

As shown in Fig. 3, the analysis and transfer system of seafloor natural gas hydrate pressure core consists of a catching and pushing unit, a cutting unit, a sonic detection device, a pressure-stabilizing unit and a subsample unit. It can transfer the core from the long gravity-piston pressure-retained corer under in-situ pressure and temperature.

The capturing and pushing unit is used for gripping and dragging the core. Considering to motions of gripping and releasing of the core, the catcher is designed to be opened and closed by ejector pins. In order to grip cores reliably, the ejector pins can be jammed into the core barrel when they are unfolded. The position of catcher is determined by a counter on the screw and controlled by programming.

The cutting unit, which consists of an oil-filled motor, a gear set, a core clamp and blades, can smoothly and quickly cut the core without disturbance at the in-situ pressure of 20MPa. The core will be gripped by the clamp while it is pulled into the cutting unit and reach the designated position, then the feeding motion of blades is activated. The gear is rotating all the time in the process of blade feeding, so that the core section is smooth. This method causes much less disturbance to the sample than cutting the core with a flat saw.

The pressure-stabilizing unit (shown in Fig. 4) is designed to keep the pressure of each cavity stable and maintain the pressure fluctuation less than 20% during the operation of the transfer system. The manual pressure pump is used to pressurize the top of the corer. Vents 1 and 2 are used to vent air from the transfer system to prevent pressure fluctuation caused by air. The ball valve 1 connects the top of the pressure-retained corer with the cavity to prevent local vacuum caused by core movement. The high-pressure pump is the power source of the pressure-stabilizing unit, which injects high-pressure water into the transfer system, and the outlet of the high-pressure pump is parallel with the overflow valve to maintain the pressure stability in the pipeline. The accumulator is used to supplement the leakage of the transfer system and to absorb pressure shocks and pulsations. The

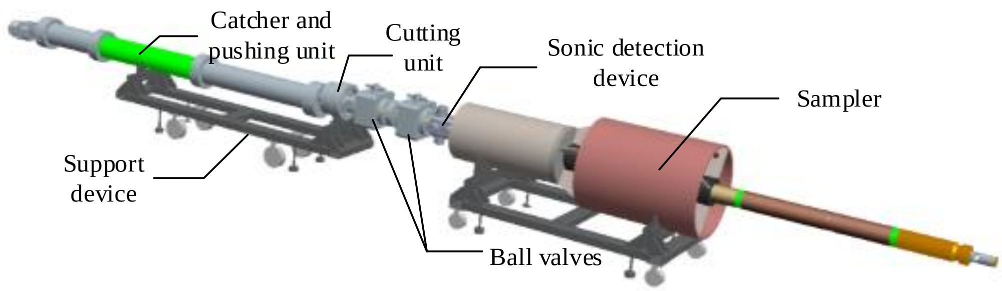

Fig.3 The analysis and transfer system

pressure gauge can display the pressure change in the transfer system in real time. The pressure sensor is used to monitor and record the pressure fluctuation in the transfer system for further analysis.

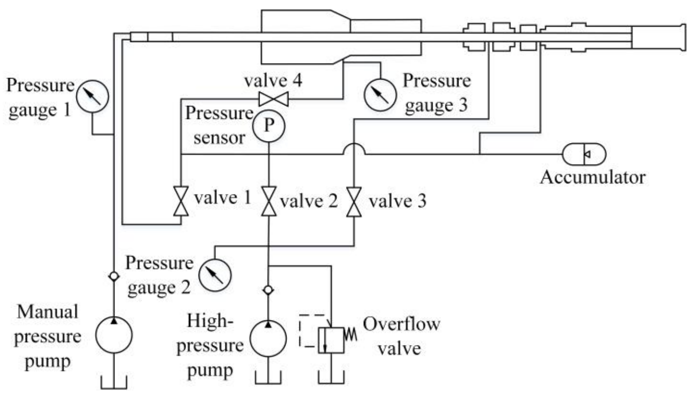

Fig.4 The pressure-stabilizing unit

The subsample unit (shown in Fig. 5) can conduct stable and undisturbed secondary sampling under the in-situ pressure up to 20MPa. The subsample unit mainly includes the following parts: the hydraulic cylinder, which provide the impetus during subsampling; the pressure-retained cylinder, is used to maintain the pressure of sample; the sample tube, is installed in the pressure-retained cylinder for the storage of samples; the connecting sleeve connects the hydraulic cylinder rod and the sampling cell.

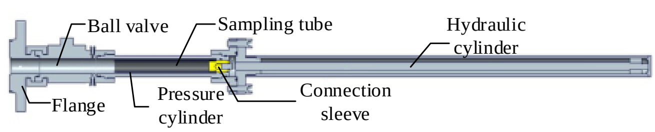

Fig.5 The subsample unit

PRINCIPLES OF OPERATION

As shown in Fig. 6, the working principles of the analysis and transfer system are divided into six stages.

Stage 1, coupling: the corer is connected to the transfer system, and the ball valves are all closed at this time. The pressure-stabilizing unit increases the pressure in the chambers of the transfer system through the branch pipes until the pressure is the same as that in the corer.

Stage 2, capturing: after equalizing the pressures, opening all ball valves. Driven by the leadscrew and nut mechanism, the catcher passes through the cutting unit, ball valve and sonic detection device successively and enters the corer to contact the core barrel. After the catcher reaches the designated position, the ejector pins are unfolded to grip the core barrel and pulls it back to the cutting unit.

Stage 3, cutting: driven by the catcher, the core barrel moves towards the cutting unit and stop in the designed position depending on the length of core to be cut. Then blades start cutting the core barrel.

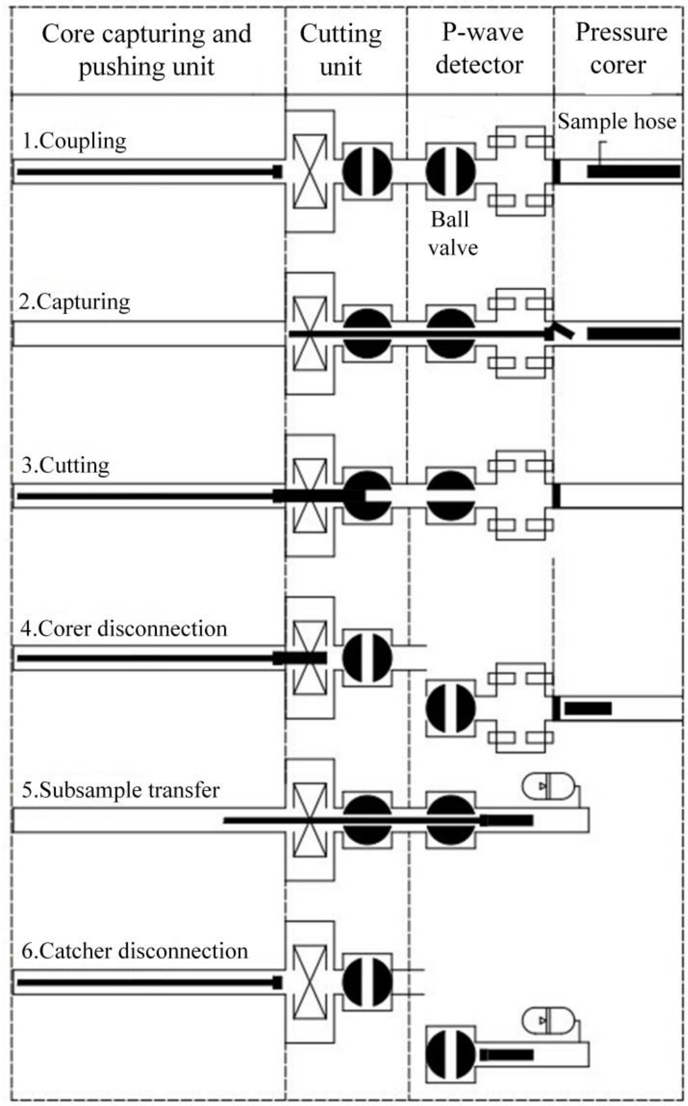

Fig.6 Operation of the pressure core transfer device

Stage 4, corer disconnection: after the core barrel is cut off, the catcher pushes the broken core barrel back to the corer to prevent the core barrel from being inside the ball valve and causing the ball valve to fail to close. After that, the catcher pulls the sub-core barrel back to the capturing and pushing unit, then closing the ball valve and separating the corer from the transfer system.

Stage 5, subsample transfer: the subsample unit 1 was butted with the transfer system, and the ball valve was opened after the pressure on both sides was balanced. Driven by the leadscrew and nut mechanism, the catcher pushes the sub-core barrel into the subsample unit 1 and pulls the remaining corer barrel back to the capturing and pushing unit. Then closing the ball valve and separating the subsample unit 1 from the transfer system. Repeating stage 5 to complete the transfer of the second sub-core barrel.

Stage 6, catcher disconnection: the subsample unit 3 was butted with the transfer system, and the ball valve was opened after the pressure on both sides was balanced. Driven by the leadscrew and nut mechanism, the catcher pushes the sub-core barrel into the subsample unit 3. After that, the ejector pins inserted into the corer barrel are retracted, then the catcher returned to the capturing and pushing unit. At this time, the ball valve is closed and the subsample unit 3 is separated from the transfer system.

SEA TRIAL

From 2006 to 2018, several experimental investigations of the long gravity-piston pressure-retained corer were carried out on the Guangzhou marine geological research vessel (voyage HY4-2006-8 and voyage HY6-11-01). Experimental data are shown in Table 2. In 2006, the first corer (1st LPC) failed to obtain core and maintain in situ pressure for the core many times. A 30-meter gravity-piston pressure-retained corer (2nd LPC) is developed based on the first corer. The most important improvement over the first corer was the addition of two water-flushing tubes; this increased the probability of obtaining natural gas hydrate core by 4-5 times. And the core had maintained the in situ pressure which was better than that of the first corer. In 2011, the length of this core barrels reached 30 m; however, only 22 m long corer barrels were used due to the limited dimension of the vessel deck. To date, the best records are that of a 14.15 m long pressure-retained sediment core at 1600 m water depth, which is the longest single column core with in situ pressure in the world so far, and an 18.5 m long core without in situ pressure. Figure 7 shows the long pressure-retained corer used during a sea trial in 2011 and the cores obtained in this sea trial.

Fig.7 Photographs of sea trial.

Table 2. Sea trial results for the long gravity-piston pressure-retained corer.

Site Name	Date	Location	L_d (m)	P_c (MPa)	L_c (cm)	M_c (kg)	Specifics of Corer
387PC	15 Aug. 2006	Paracel Islands	1400	0	900	1300	OD 105 mm; ID 75 mm
373PC	16 Aug. 2006	Paracel Islands	1400	14	900	1300	OD 105 mm; ID 75 mm
DSH-1	19 Aug. 2006	Pratas Islands	3150	0	160	1300	OD 105 mm; ID 75 mm
DSH-1	19 Aug. 2006	Pratas Islands	3050	0	0	1300	OD 105 mm; ID 75 mm
DSH-1	20 Aug. 2006	Pratas Islands	3050	0	753	1300	OD 105 mm; ID 75 mm
DSH-1A	20 Aug. 2006	Pratas Islands	3050	30	658	1300	OD 105 mm; ID 75 mm
DSH-1C-1	22 Aug. 2006	Pratas Islands	3050	32	659	1300	OD 105 mm; ID 75 mm
DSH-1C-2	22 Aug. 2006	Pratas Islands	3050	0	624	1500	OD 105 mm; ID 75 mm
DSH-7	23 Aug. 2006	Pratas Islands	3050	32	957	1500	OD 105 mm; ID 75 mm
DSH-9	23 Aug. 2006	Pratas Islands	3050	34	957	1500	OD 105 mm; ID 75 mm
DSH-1D	24 Aug. 2006	Pratas Islands	3050	0	963	1500	OD 105 mm; ID 75 mm
DSH-13	24 Aug. 2006	Pratas Islands	3050	0	884	1500	OD 105 mm; ID 75 mm
Jiulong Reef	25 Aug. 2006	Jiulong Reef	760	9	20	1500	OD 105 mm; ID 75 mm
Jiulong Reef	25 Aug. 2006	Jiulong Reef	760	2	500	1500	OD 105 mm; ID 75 mm
BZ888	9 May 2006	115°26.0922' E/19°18.8040' N	2470	0	944	1300	OD 105 mm; ID 75 mm
BZ526PC	26 May 2006	111°47.0962' E/17°45.1193' N	1940	20	915	1300	OD 105 mm; ID 75 mm
DHCL12	17 Apr. 2011	118°47.4258' E/22°00.8804' N	1023	9.5	12.1	1800	OD 112 mm; ID 90 mm
DHCL13	25 Apr. 2011	118°44.6179' E/22°01.5884' N	850	8.8	9.7	2500	OD 112 mm; ID 90 mm
973-4	22 Apr. 2011	118°49.0818' E/21°54.3247' N	1600	16.5	14.5	2500	OD 112 mm; ID 90 mm
9735	26 Apr. 2011	119°11.0066' E/21°18.5586' N	3050	0	9.65	2500	OD 112 mm; ID 90 mm
PPC1	20 May 2011	116°53.4988' E/17°51.9969' N	4000	2	18.5	2500	OD 112 mm; ID 90 mm

Notes: Ld = water depth; Pc = coring pressure; Lc = length of the coring; Mc = the total weight of the corer.

In 2016, two experimental investigations of the analysis and transfer system of seafloor natural gas hydrate pressure core were carried out in the South China. The corer used in this sea trial is the 30-meter gravity-piston pressure-retained corer (2nd LPC) shown in this paper. The outer diameter of the core is 73 mm and the inner diameter is 67 mm, only 3 m long corer barrels were used due to the limited dimension of the transfer system. Figure 8 shows the coupling of the pressure-retained corer and the transfer system.

Fig.8 Pressure-retained transfer trial on board

The first pressure-retained transfer is carried out at the pressure of 13Mpa and the second is carried out at the pressure of 20Mpa. The pressure-retained transfer time is less than 3 hours. After cutting, subsamples with a length of 0.83 m and an external diameter of 67mm can be obtained. During the transfer process, the system can realize automatic overflow to ensure stable pressure, and the pressure fluctuation is less than 10%. Figure 9 shows the subsamples without in situ pressure

Fig.9 Subsamples without in situ pressure

CONCLUSIONS

Pressure-retained coring and pressure-retained transfer are an organic combination. Pressure-retained corer can realize in-situ coring, but further analysis of in-situ cores cannot be realized in the laboratory without the analysis and transfer system. This paper illustrates overall structure and principles of operations of the analysis and transfer system of seafloor natural gas hydrate pressure core. Two pressure-retained coring and transfer trial have been carried out in the South China Sea. The fluctuations are both less than 10% of the system pressure, which means that the transfer system has an excellent performance on pressure maintenance. Nevertheless, the temperature-retained performance in this system is still an issue, which are to be solved in the further research.

Compared with offshore drilling, the pressure-retained corer in this paper has the advantages of flexibility and maneuverability, and the development cost is relatively low. The technique of pressure-retained transfer makes the pressure-retained coring play a great role in the exploration and development of gas hydrate and makes the core be treated and analyzed scientifically and reasonably.

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