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Gas-Liquid Separation Processes for Mud Logging Systems

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Abstract: The TRU-Vision system, developed by Baker Hughes, analyzes the gas extracted from drilling mud to estimate the hydrocarbons composition in drilled rock formations. Several separation processes had been surveyed in order to enhance the gas extraction at the gas trap, namely, mechanical stirring, vacuum, air sparging, membrane separation processes, ultrasounds, and cyclones. Mechanical stirring devices (one propeller, one flat-blade turbine, and two baffles sets), a vacuum generator, and an air bubble generator were designed and assembled to increase the efficiency and the response stability of TRU-Vision system.

Key words: Air sparging, gas extraction, mechanical stirring, mud logging, vacuum.

Nomenclature

C_{BF}	Baffle clearance [mm];
C_i	Impeller clearance [mm];
D_i	Impeller diameter [mm];
D_T	Gas trap diameter [mm];
H_L	Mud height [mm];
L_B	Impeller blade length [mm];
P_1, P_2	Bubble internal pressures [bar];
V_1, V_2	Bubble volumes [m^3];
W_B	Impeller blade width [mm];
W_{BF}	Baffle width [mm].

Abbreviations

CVD	Constant volume degasser (gas trap);
3D	Three dimension.

1. Introduction

The TRU-Vision apparatus (Fig. 1), developed and manufactured by Baker Hughes, analyzes the gas extracted from drilling mud to estimate the hydrocarbons composition in the drilled rock formations. For example, the ratios CH_4/C_2H_6, CH_4/C_3H_8, and CH_4/C_4H_{10} enable the identification of rock formation variations and the estimation of reservoir productivities [1, 2], according to Table 1. Gas chromatography is an extremely useful tool to identify and quantify the light-hydrocarbons extracted from a drilling mud.

The TRU-Vision consists of a compact device that continuously collects drilling mud samples, heats the mud, extracts the gases from the mud in a gas trap, conditions and analyzes the gases in a gas chromatograph. It is of paramount importance to enhance the gas extraction at the gas trap, and thereby augment the efficiency and response stability of TRU-Vision. Although TRU-Vision already yields high quality data, the following features may be further improved: higher and more stable efficiency of the gas extraction from the drilling mud, less maintenance and utilities required, lower weight and costs.

The major physical mechanisms underlying the gas extraction (from liquids and/or solids) are the outgassing, degassing and desorption. Outgassing consists in the gas spontaneous release from a material. Degassing designates gas forced extraction. Desorption denominates the release of adsorbed chemicals from a material

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Fig. 1 TRU-Vision apparatus.

Table 1 Ratios of light-hydrocarbons concentrations and corresponding reservoirs productivities [3].

Ratio	Oil	Gas	Unproductive
CH_4/C_2H_6	2 to 10	10 to 35	< 2 and > 35
CH_4/C_3H_8	2 to 14	14 to 82	< 2 and > 82
CH_4/C_4H_{10}	2 to 21	21 to 200	< 2 and > 200

surface [4]. As for the gas extraction from a drilling fluid, only the outgassing and degassing methods may be applied, because the gas is present in the drilling mud mainly in the form of dissolved microbubbles. The most common techniques for degassing the gas present in a drilling mud are mechanical stirring, vacuum, air sparging, heating, membrane separation processes, ultrasounds, and cyclones.

1.1 Mechanical Stirring

The mechanical stirring in the gas trap aims at inducing a high turbulence to the mixture gas/mud to promote the release of the entrained gas in the mud [5], and the increase of the contact surface area between the gas and the mud, yielding a fast mixing of the gas with fresh air such that the ditch line composition is representative of the gas/mud concentration, and maintaining a constant gas release regardless mud level fluctuations inside the gas trap [6, 7].

A high stirring velocity (Reynolds number ~10^6) is required throughout degassing, to strongly promote the gas rise through the mud, analogously to von Kármán swirling flow [8]. High turbulence may be induced by given stirrer types, depending on the fluid viscosity [9].

1.2 Vacuum

The gas dissolved in a liquid under reduced pressure becomes less soluble, depending on the liquid area exposed to vacuum [10]. Furthermore, a less soluble gas separates more easily from the liquid [11].

1.3 Air Sparging

According to Boyle's law, the volume and pressure of a bubble are inversely proportional at constant temperature [12]:

$$P_1 \times V_1 = P_2 \times V_2 \quad (1)$$

The continuous injection of air at the gas trap bottom forces the air bubbles to collide with the methane microbubbles [13]. The air bubbles volume is higher than the methane microbubbles volume, because the lower internal pressure of the air bubbles promotes the Ostwald ripening effect. The methane microbubbles collide and easily coalesce with the air bubbles to equilibrate both bubbles pressures. The merged bubble volume increases and it rises faster to the surface, due to the buoyancy force, where the methane is finally released [14]. A higher amount of methane will be released in the presence of a turbulent air sparging.

1.4 Membrane Separation Processes

Certain selective membranes are only permeable to gases [15]. In such a case, by flowing the drilling mud as the membrane feed and maintaining the membrane permeate under vacuum, the gases dissolved in the mud permeate through the membrane [16, 17]. This membrane operation is known as Gas Separation (Fig. 2).

1.5 Ultrasounds

Ultrasounds are commonly applied to remove small bubbles and dissolved gases from liquids [18]. The sound waves, while propagating through a liquid, alternate between cycles of high pressure (compression) and low pressure (rarefaction). In rarefaction, if many near-vacuum bubbles are created, a large contact surface area with the liquid is obtained. The dissolved methane may migrate to these low pressure bubbles, increasing their volume and inducing their fast rise. Ultrasounds show the advantage of reduced gas redissolution, as the fast rise of bubbles diminishes the contact time [19, 20].

1.6 Cyclones

In cyclone separators, the centrifugal force splits fluid components with distinct phases and/or densities. In a cyclone, the fluid and a carrier gas enter into a conical vessel, being projected tangentially to the wall [21]. The heavier compounds (higher densities) flow downwards along the wall and leave the vessel through the bottom outlet whereas the lighter compounds (lower densities) exit the vessel through the top outlet [22, 23] (Fig. 3). As the drilling mud and the air are projected against the wall, small droplets are created, yielding a large contact surface area between the mud and the air, thereby facilitating the transfer of methane to the air [24, 25].

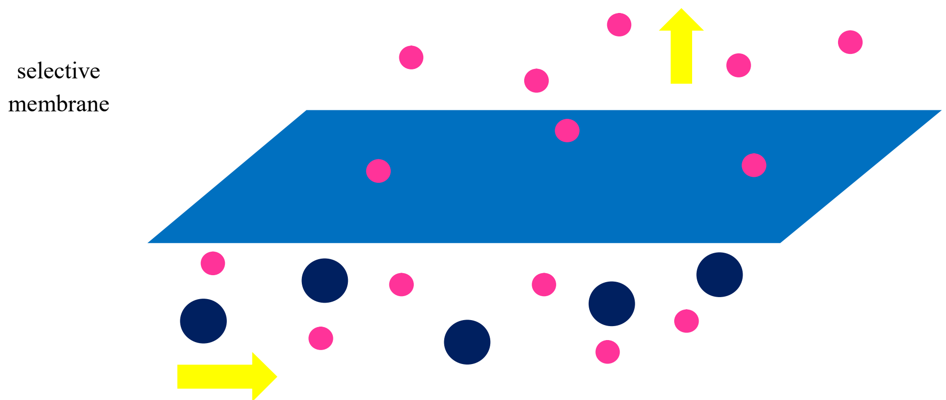

Fig. 2 Separation of gas (pink circles) from drilling mud (blue circles).

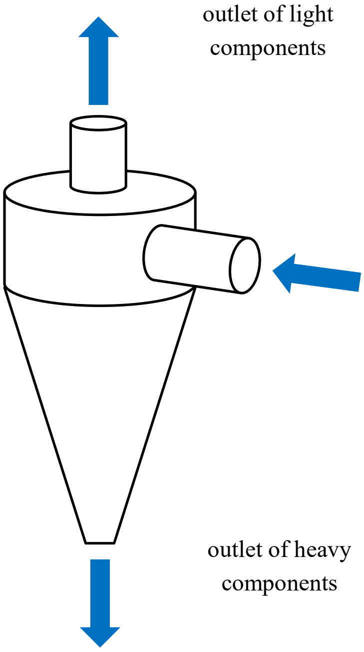

Fig. 3 Multiphase cyclones.

2. Materials and Methods

Mechanical stirring and vacuum were previously optimized in TRU-Vision gas trap [26], but both methods may be further enhanced. In this work, various improved devices for mechanical stirring, vacuum generation and air sparging had been designed, manufactured and assembled to intensify the gas extraction from the drilling mud in the gas trap, and thereby augment the efficiency and response stability of TRU-Vision.

2.1 Mechanical Stirring

Bearing in mind that the drilling mud viscosity was about 10^2 cP [27], the impeller types selected were the propeller (applicable to fluids with viscosities in the range 1-10^4 cP) and the flat-blade turbine (applicable to fluids with viscosities in the range 1-3.2×10^4 cP).

A three-blade propeller generates an axial flow and it is commonly used at high rotational velocities (1,750 rpm) corresponding to Reynolds numbers higher than 200. The flat-blade turbine is usually applied for gas-liquid dispersions at low flow rates of gas in small vessels [28].

The impellers selected (propeller and flat-blade turbine) had been designed based on thumb rules and geometric specifications [9, 28] (Fig. 4). Both impellers had been printed in stainless steel in a 3D printer (Table 2 and Fig. 5).

Baffles prevent settling and stagnant zones throughout the stirring of viscous fluids and/or fluids containing-particles, such as drilling muds. The current CVD (Constant Volume Degasser) gas trap has three straight baffles adjacent to the wall. As the mud viscosity, ca. 10^2 cP [27], is low to moderate, a three-baffle set apart and perpendicular to the gas trap wall and a four-baffle set adjacent and perpendicular to the gas trap wall were designed based on thumb rules. Both baffle sets had been printed in titanium in a 3D printer (Fig. 6).

2.2 Vacuum

A set of devices was assembled to generate vacuum in the gas trap (Fig. 7). A needle valve (*Parker* Series 9) was located at the air inlet hose of the gas trap, and electrically connected to a wave generator (*Agilent* 33210A) and a power supplier (*TDL-Lambda* X600). The wave generator controlled the valve opening time.

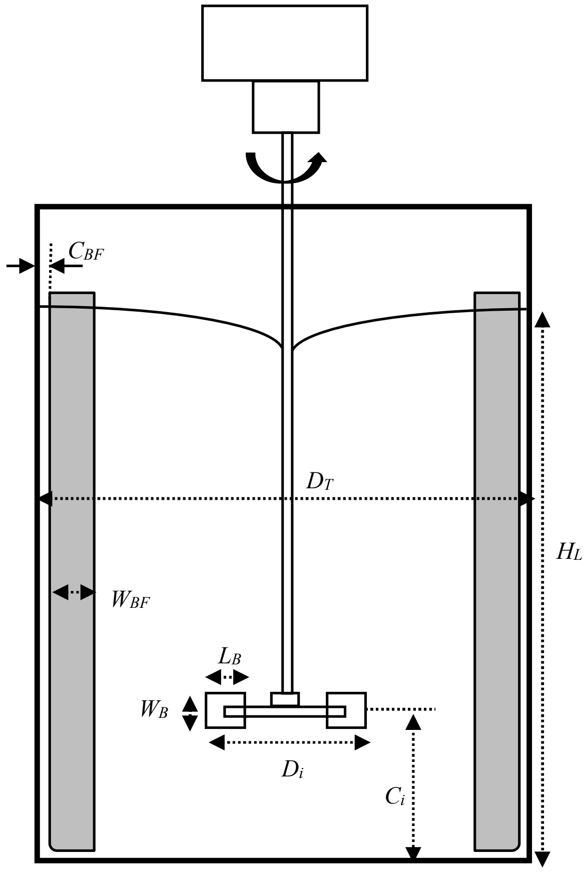

Fig. 4 Scheme of stirred gas trap.

Table 2 Geometric specifications of stirred gas trap.

Impeller	D_i/D_T	C_i/D_T
Propeller	0.33	0.25
Flat-blade turbine	0.33	0.25

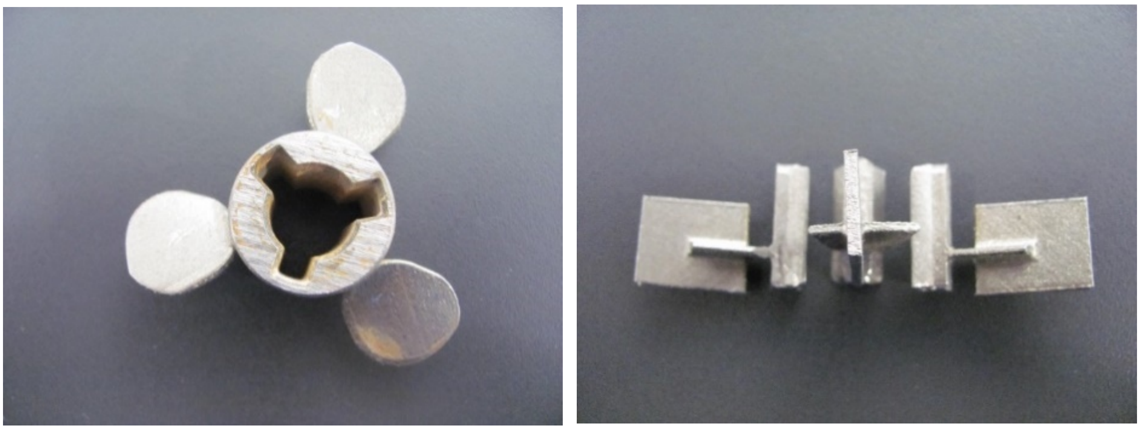

Fig. 5 3D printed impellers in stainless steel. On the left-hand side: propeller (blades assembled on the shaft adaptor) and on the right-hand side: flat-blade turbine (only the blades).

Fig. 6 3D printed baffles in titanium. On the left-hand side: three baffles set apart from the gas trap wall and on the right-hand side: four baffles set adjacent to the gas trap wall.

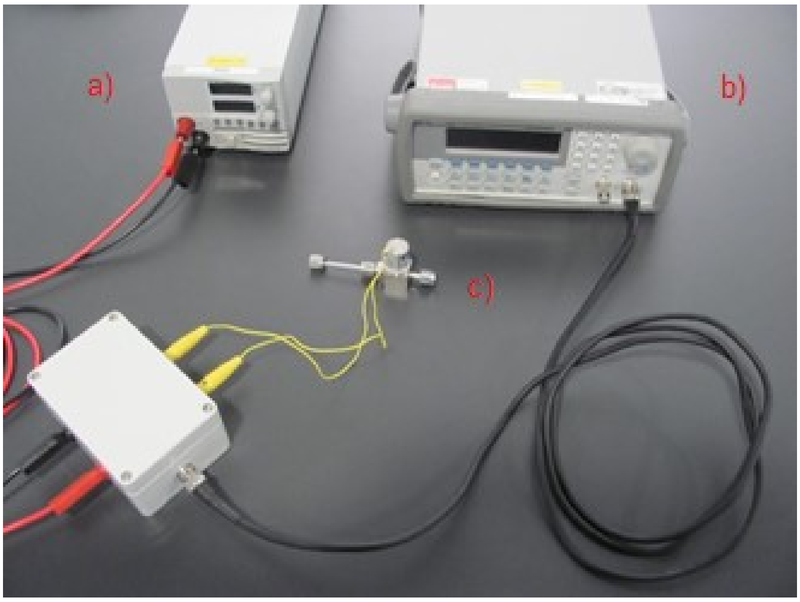

Fig. 7 Gas trap vacuum generator: a) power supply, b) wave generator, c) needle valve.

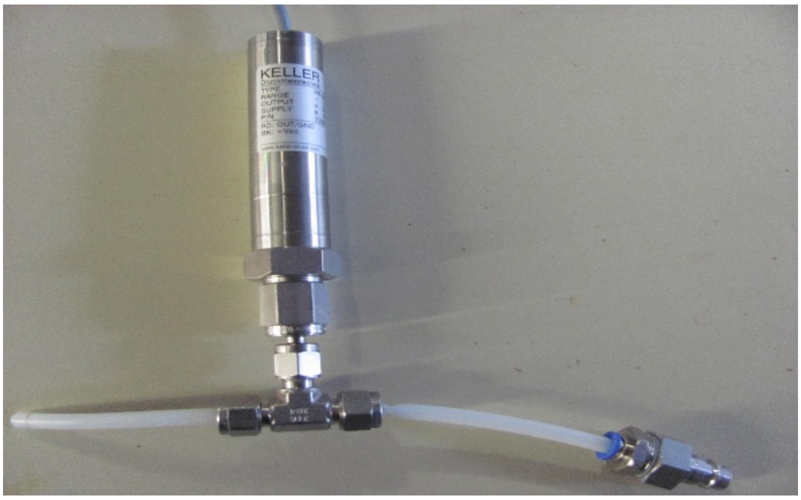

Fig. 8 In-line pressure sensor.

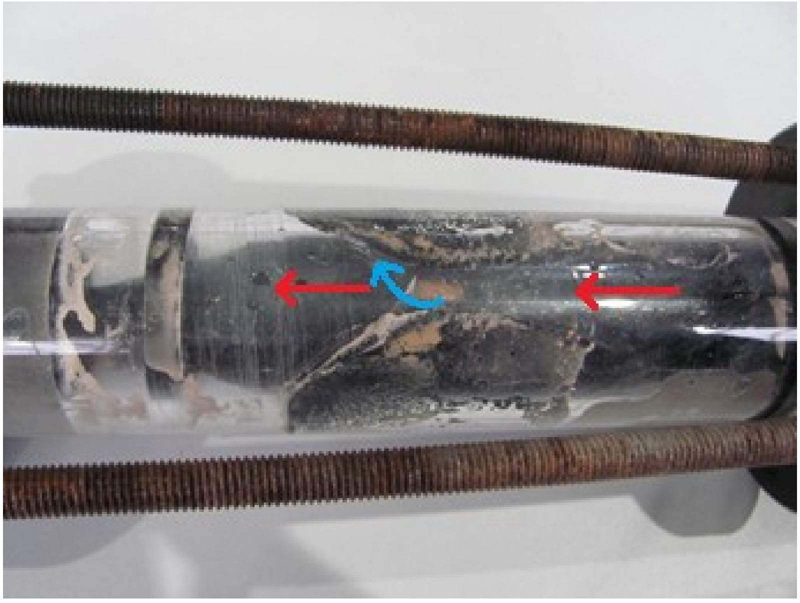

Fig. 9 Bubble generator prototype (empty). The red and blue arrows indicate the mud path and the gas injection into the mud through the porous material, respectively.

The valve restriction and the continuous suction of air into the ditch line resulted in a pressure drop inside the gas trap. A pressure sensor (*Keller* PR-23Ed, Fig. 8) was assembled in-line at the beginning of the ditch line to measure the pressure therein and estimate the gas trap pressure. It was connected to a media logger (*Graphtec* medi LOGGER GL220), in which the pressure data were displayed and recorded.

2.3 Air Sparging

To enhance the air sparging process (Fig. 9), a bubble generator had been inserted with the air flow rate controlled by a needle valve, connected to the pressurized air facility [29].

Throughout this work, previously built bubble generators were used but failed after a while, i.e. they did not produce microbubbles any longer (only macrobubbles). Their failure might have been due to the erosion of the porous material by the high flow rates of the drilling mud.

3. Results and Discussion

Although the current design of TRU-Vision gas trap is simple, robust, and stable as previously demonstrated in Ref. [26], potential improvements of the gas extraction at the gas trap were assessed in the present work.

The current mechanical stirring of the gas trap may be further enhanced concerning the gas extraction efficiency and stability, the weight and utilities (e.g. air) relief. The gas extraction delays for small contact surface areas, thus a vortex would be beneficial, likewise for the application of vacuum and/or air sparging.

The major handicap of vacuum creation is the mud aspiration into the ditch line at pressures below the atmospheric pressure, damaging downstream equipment. However, vacuum may be applied together with other processes proposed herein.

The application of air sparging in TRU-Vision is unpractical. A bubble generator or another air bubble injector located at the gas trap bottom or mud inlet would be ruined by the drilling cuttings. A better option would be the application of air sparging through the impeller rod but it would imply the gas trap redesign.

Although a gas permeable membrane would prevent gas redissolution, it would require the gas trap redesign and vacuum implementation, as well. Moreover, membranes cannot handle the drilling cuttings contained

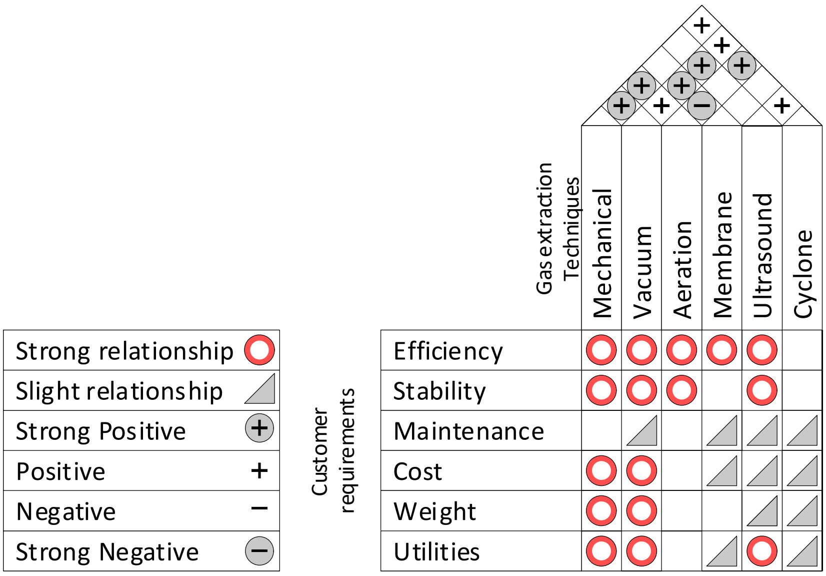

Fig. 10 House of Quality diagram including customer requirements and gas extraction techniques.

in the mud, and their frequent replacement and maintenance would be prohibitive. Even though ultrasounds apparatus are efficient and fast, the gas trap redesign would be required, besides the apparatus maintenance and cost. As cyclones rely on centrifugal forces, the gas trap redesign and high flow rates of the drilling mud would be required. The processes that would demand the redesign of TRU-Vision gas trap have been dropped since the project determined to maintain the current gas trap dimensions.

The coupling of the potential processes that would enhance the gas extraction in the gas trap is depicted in Fig. 10. Clearly, mechanical stirring and vacuum are more advantageous than the other processes. Still, it is worth remarking that only experimental tests would absolutely rank the processes efficiency and stability.

4. Conclusions

The TRU-Vision is a mud logging system to extract and analyze the gas extracted from drilling muds, in order to estimate the hydrocarbons composition in drilled rock formations. A TRU-Vision prototype comprised a methane bubble generator and a gas trap, the operating conditions of which were previously optimized [26].

In this work, various processes were surveyed to enhance the gas extraction efficiency in the CVD gas trap, namely, mechanical stirring, vacuum, air sparging, membrane separation processes, ultrasounds, and cyclones. As mechanical stirring, vacuum, and air sparging would not require the gas trap redesign, these alternatives had extra devices designed and assembled, viz. one propeller, one flat-blade turbine, two sets of baffles, a vaccum generator, and an air bubble generator, which have not been tested in the lab yet. From the surveyed methods, vacuum is the easiest to implement and surely will increase the gas extraction efficiency in the next TRU-Vision model. The bubble generator requires enhancements to augment its lifespan. The monitoring and control of the bubbles sizes is relevant, as well. It is also pertinent to determine the mud composition ranges in which the gas microbubbles are entrapped.

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References

[1] Hammerschmidt, S. B., Wiersberg, T., Heuer, V. B., Wendt, J., Erzinger, J., and Kopf, A. 2014. "Real-Time Drilling Mud Gas Monitoring for Qualitative Evaluation of Hydrocarbon Gas Composition during Deep Sea Drilling in the Nankai Trough Kumano Basin." *Geochemical Transactions* 15 (article no. 15). https://doi.org/10.1186/s12932-014-0015-8.

[2] Hashimov, S. 2015. "Gas Ratio Analysis in Hovsan Oil Field." *Journal of Geological Resource and Engineering* 3 (1): 42-8. doi: 10.17265/2328-2193/2015.01.006.

[3] Baker Hughes INTEQ. 1996. "Evaluation of Hydrocarbon Shows." In *Wellsite Geology*. Houston, Texas, USA, pp. 3-10 – 3-21.

[4] Chiggiato, P. 2006. "Outgassing." CERN, Technology Department, CERN Accelerator School, Geneva, Switzerland.

[5] Lucena, R. 2012. "Extraction and Stirring Integrated Techniques: Examples and Recent Advances." *Analytical and Bioanalytical Chemistry* 403 (8): 2213-23.

[6] Wright, A., Hanson, S., DeLaune, P., McKinzie, H., and Aghazeynali, H. 1993. Patent No. 5199509. USA.

[7] Li, H., Ye, D., Zou, C., and Xue, Z. 2015. "Numerical Investigation of Degas Performance on Impeller of Medium-Consistency Pump." *Journal of Advances in Mechanical Engineering* 7 (12): 1-9.

[8] Zandbergen, P. J., and Dijkstra, D. 1987. "Von Kármán Swirling Flows." *Annual Review of Fluid Mechanics* 19: 465-91.

[9] Doran, P. 1995. *Bioprocess Engineering Principles* (Vol. 1). London, UK: Academic Press.

[10] Van Slyke, D. D., and Neill, J. M. 1924. "The Determination of Gases in Blood and Other Solutions by Vacuum Extraction and Manometric Measurement." *The Journal of Biological Chemistry* 61 (2): 523-73.

[11] Nourozieh, H., Kariznovi, M., and Abedi, J. 2016. "Measurement and Correlation of Solubility and Physical Properties for Gas-Saturated Athabasca Bitumen." *Society of Petroleum Engineers Production & Operations* 31 (3): 207-18.

[12] ASME Shale Shaker Committee. 2005. *Drilling Fluids Processing Handbook* (Vol. 1). Burlington, MA, USA: Elsevier.

[13] Hu, L., Wu, X., Liu, Y., Meegoda, J. N., and Gao, S. 2010. "Physical Modeling of Air Flow during Air Sparging Remediation." *Environmental Science and Technology* 44 (10): 3883-8.

[14] Schmelzer, J., and Schweitzer, F. 1987. "Ostwald Ripening of Bubbles in Liquid-Gas Solutions." *Journal of Non-Equilibium Thermodynamics* 12 (3): 255-70.

[15] Chen, X. Y., Vinh-Thang, H., Ramirez, A. A., Rodrigue, D., and Kaliaguine, S. 2015. "Membrane Gas Separation Technologies for Biogas Upgrading." *The Royal Society of Chemistry Advances* 5 (31): 24399-448.

[16] Tonner, D., Al-Maslout, K., Pinna, G., Forber, D., Davies, W., Chopty, J., and Jaipersad, M. 2011. "The Benefits and Application of Semi-Permeable Membrane Surface Gas Detection during Managed Pressure Drilling." Presented at the Brasil Offshore, Macaé, Brazil, June 2011. Paper No. SPE-143085-MS.

[17] Separel. 2015. "Hollow Fiber Membrane Module." Accessed June 28, 2021. http://www.separel.com/en/.

[18] Pandey, N., Murugesan, K., and Thomas, H. R. 2017. "Optimization of Ground Heat Exchangers for Space Heating and Cooling Applications Using Taguchi Method and Utility Concept." *Journal of Applied Energy* 190: 421-38.

[19] Leighton, T. G. 1994. "The Acoustic Bubble." *Journal of Fluid Mechanics* 272: 407-9.

[20] Wu, T. Y., Guo, N., Teh, C. Y., and Hay, J. X. W. 2013. *Advances in Ultrasound Technology for Environmental Remediation*. London, UK: Springer Science & Business Media.

[21] Kepa, A. 2013. "Experimental Investigations of Additional Gas Extraction inside a Cyclone." *Archives of Thermodynamics* 34 (4): 247-56.

[22] Shields, S. 2015. "Give It a Whirl." Accessed June 28, 2021. https://www.sulzer.com/fr/Newsroom/Sulzer-Technical-Review/STR-Library/STR-Issue-1-2015/Give-it-a-Whirl?type=blank.

[23] ASCOMPTransAT. 2014. "Gas-Liquid Cyclone Separator." Accessed June 28, 2021. https://www.youtube.com/watch?v=Zzj7oORL3gw.

[24] Hoffmann, A. C., and Stein, L. E. 2002. *Gas Cyclones and Swirl Tubes—Principles, Design and Operation* (2nd ed., Vol. 1). Bergen, Norway: Springer.

[25] Coker, A. K. 2007. *Ludwig's Applied Process Design for Chemical and Petrochemical Plants* (4th ed., Vol. 1). Oxford, UK: Elsevier.

[26] Marum, D. M., Afonso, M. D., and Ochoa, B. B. 2020. "Optimization of the Gas-Extraction Process in a New Mud-Logging System." *Society of Petroleum Engineers, SPE-198909-PA, SPE Drilling & Completion* 35 (1): 1-13. doi: 10.2118/198909-PA.

[27] Marum, D. M., Afonso, M. D., and Ochoa, B. B. 2020. "Rheological Behavior of a Bentonite Mud." *Applied Rheology* 30 (1): 107-18. doi: 10.1515/arh-2020-0108.

[28] Walas, S. M. 1988. *Chemical Process Equipment—Selection and Design*, edited by H. Brenner. Kansas, USA: Butterworth-Heinemann Series in Chemical Engineering.

[29] Ochoa, B., Ritzmann, N., and Wessling, S. 2014. Patent No. SLG4-58187-US. Germany.