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Analysis of offshore LNG storage and transportation technologies based on patent informatics

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ABSTRACT

As International Maritime Organization (IMO) 2020 Regulations on sulphur limits took effects, increasing interests in LNG are witnessed worldwide, since LNG is believed to be a promising alternative for the reduction of air pollution. The aim of this paper is to study the technological advancements of offshore LNG storage and transportation technologies based on patent informatics. Patent informatics is the analysis of patents in order to unveil patent information. In this work, past patenting activities in the studied technological domain were reviewed, the most active technological participants were identified, worldwide patent portfolios were constructed, and text mining and clustering of the key technologies were conducted. Results of the study can help to identify technological opportunities in the area of offshore LNG storage and transportation, and may serve as a reference for decision makers to formulate strategic plan for future technological development.

1. Introduction

In recent years, the global demand for natural gas exhibits a fast rising trend. LNG, the liquefied natural gas, which has a volume around 1/600 that of the natural gas at room temperature, is becoming a major gas export method worldwide (Thomas and Dawe, 2003). The liquefaction of natural gas not only increases its storage capacity, but also offers a safer and more economical way for natural gas transportat (Kumar et al., 2011).

Since the global emissions of CO_2 is expected to rise drastically by 30% during the period from 2005 to 2030 (Exxonmobil, 2009), there exists an absolute need for cleaner and more efficient energy sources in order to restrain CO_2 emissions while at the same time meet the increasing energy demand. Apart from a direct cut of approximately 71% on CO emission and 23% of CO_2 emission (Zárante and Sodré, 2009), LNG fuel considerably reduces emissions of sulphur oxides (SO_X), nitrogen oxides (NO_X) and particulate matter (PM) by 85~100% (Kim and Seo, 2019). As the cleanest fossil fuel, it was reported that the global consumption of LNG grew by 12.5%–359 million tonnes in 2019 (Shell, 2020).

After International Maritime Organization (IMO) 2020 Regulations on sulphur limits took effects, interests in LNG will continue to increase, since LNG is believed to be a promising alternative for the reduction of air pollution, particularly emitted from the ships (Zhu et al., 2020). Consequently, the need for building up LNG carriers and facilities for its processing, storage and transportation also increases drastically (Animah and Shafiee, 2020). According to *2020 World LNG Report*, by the end of 2019, 42 new vessels, including 34 FSRUs (Floating Storage Regasification Units) and 4 FSUs (Floating Production and Storage Units), were added to the total 541 active vessels worldwide (International Gas Union, 2020).

With the increasing interests in LNG, many studies have been focused on this type of energy resource. Recent developments on the floating liquefied natural gas (FLNG) from the perspective of hydrodynamics, including multi-body floating systems, tank sloshing, coupled FLNG and the mooring systems, and stabilities of the single-point mooring FLNG systems, are reviewed by Zhao et al. (2011). Current status of the liquefaction capabilities of LNG plants are discussed by Lim et al. (2013). Current trends for FLNG technologies, including gas pre-treatment and liquefaction, FLNG Hull and mooring systems, as well as LNG offloading systems are explained by Won et al. (2014). Recent advancements, including numerical simulations, scaled model tests and full scale measurements, of hydrodynamics associated with side-by-side offloading are reviewed by Zhao et al. (2018). Besides, Animah and Shafiee (2020a,b) presented an overview of risk analysis models in the LNG carriers, LNG terminals, LNG plants, FLNGs, etc.

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The industry of offshore LNG storage and transportation is making rapid progress. However, little studies have conducted a comprehensive patent analysis to explore the key technologies for offshore LNG storage and transportation, hence the necessity for this present paper. A patent is a representation of an invention in a certain technological field, and a great majority of the information provided in patent documents is in fact relatively novel. Over 80% of the information published in patents never appears in any other information sources (Dou and Clerc, 2015). A comprehensive analysis of patent data can help to review past patenting activities, forecast future technological trends, develop strategic plan for technology advancements, identify promising patents and technological competitors, as well as identify technological hotspots and vacuums (Abbas et al., 2014a,b).

In this paper, the development trend of offshore LNG storage and transportation technologies is analyzed based on patent informatics, and the rest of the paper is organized as follows. Firstly, a literature review on the state-of-the-art in patent analysis is performed. Secondly, data retrieval process and the methodology adopted are explained. Thirdly, the global application and the geological distribution patterns for patenting activities, as well as patent assignees and their patent portfolios are analyzed; besides, cluster analysis for the terminologies to identify key technologies related to offshore LNG storage and transportation based on text mining is conducted. Finally, the last section concludes the study.

2. Literature review of patent analysis

A typical patent analysis task consists of a series of steps, including searching and retrieving patent documents from patent databases, abstracting information from patents, clustering of patents, as well as visualization and interpretation of patent information (Trappey, 2014). Bibliometrics is an approach widely adopted in patent analysis. The concept of bibliometrics was first put forward by Pritchard (1969), who defined it as a method to analyze scientific literature in order to reveal the general research patterns of a certain domain, based on statistics (Andreo-Martínez, 2020). Narin (1994) extended the application of bibliometrics in patent analysis and proposed the term "patent bibliometrics" which becomes a means for the analysis of patent documents in order to evaluate specifically the technological activities.

Traditional patent analysis relies heavily on the expertise of professional patent searchers and analysts, and often involves laborious tasks of manual analysis of patent documents (Abbas et al., 2014a,b). Recent development of automatic tools for patent analysis helps to facilitate the analysis process. The analysis of patents using automatic tools in order to unveil patent information which is presented through the visualization of cooperation and citation networks, as well as text mining of patent data, is termed as patent informatics (Bonino et al., 2020). In spite of a young discipline, patent bibliometrics and informatics has already been applied to a wide range of sectors. Liu (2013) explored terahertz technology through a combination analysis of patents and journal articles, where general information analysis of patents and articles, cluster analysis, cooperation and citation analysis, etc. are conducted and visualized. Similarly, Zhang et al. (2018) provided an analysis of both the patents and journal articles regarding solid dispersions based on publication trends, cooperation and citation networks, text mining and science mapping. Kim et al. (2019) conducted a patent analysis to identify emerging technologies and vacant technological areas of wireless power transfer, adopting such methods as time series analysis, text mining and clustering. Wang et al. (2020) investigated development trajectory of digital twin based on a patent map analysis. Durmusoglu and Durmusoglu (2020) analyzed all traffic control system-related patents issued during the period from 2009 to 2018 in order to reveal its technological developments.

3. Data and methodology

The present paper studies the development of offshore LNG storage and transportation technologies through patent informatics. This research started with a bibliographic search of patent documents by retrieving keywords ("liquefied natural gas" OR "liquid natural gas" OR LNG) AND (storage OR transport*) AND (offshore OR sea OR ocean OR maritime) while excluding the following IPC categories, i.e. C04 OR C07 OR C02 OR E21, from Derwent Innovation. The query was made based on the keywords retrieved from the title, abstract and claim fields of patents. By eliminating the irrelevant results, altogether 689 patents families were obtained up to May 14, 2020. Since patents are territorial, a separate patent needs to be filed in each country where the patent protection is necessary. A patent family include a series of patents which protect the same invention but with different patent numbers.

Geological distribution patterns of patents on offshore LNG storage and transportation were obtained according to application numbers both by year and by application country; the most active patent assignees and their patent portfolios based on International Patent Classification (IPC) codes were analyzed; besides, *ITGInsigh* (Liu et al., 2015), a text mining and visualization tool, was adopted for the cluster analysis of the key technologies in the domain of offshore LNG storage and transportation.

4. Results and discussions

4.1. Geological distribution patterns

According to the worldwide patent application growth shown in Fig. 1, the patenting activities regarding offshore LNG storage and transportation starts in the late 1960s, and the following three decades only witnessed a small amount of applications. Data indicates that the first patent application was made by Chiyoda Corporation on "Direct regasification of liquefied natural gas by heat exchange with water" (Patent No. JP48003884B Corp, 1969) in 1969. This patent offered a method of using sea water for heating LNG, and suggested making use of the cooled sea water through heat exchange with LNG for steam power generation. In fact, the first time LNG transported by sea was in 1959, when Methane Pioneer carried LNG from the Gulf of Mexico to Convey Island in England. However, the refrigerating capacity of LNG was not utilized at that time (Dean, 1966).

From the year 2000, the number of patent applications starts to increase drastically, and in 2018, the number of applications peaked at 67. The application spurt happens during the rapid development witnessed

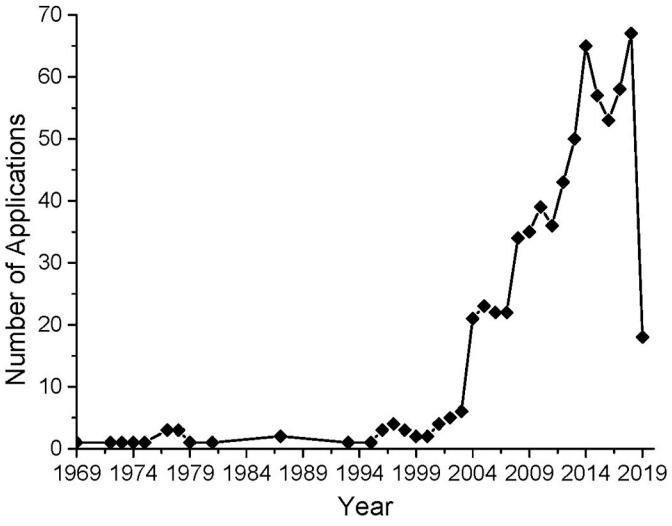

Fig. 1. Global patent growth according to application year.

in the LNG shipping industry. Since the disclosure of patent documents usually takes around 18 months, hence the application statuses in 2019 and 2020 are for reference only. Fig. 2 illustrates the total application numbers of the worldwide patenting countries in the domain of offshore LNG storage and transportation. South Korea filed the largest number of patents, taking up around 1/3 of the global applications. USA and China are neck and neck in patenting activities, both having filed over 100 patents. Besides, there are respectively 37 and 4 patents which were applied through European Patent Office and World Intellectual Property Organization.

Data also shows that among the most active five patenting countries, only Japan and USA filed patents before 2000, as shown in Fig. 3. The patents of Japan during this period were focused on technologies regarding LNG regasification (Patent No. JP48003884B Corp, 1969), welding (Patents No. JP63207496A Nippon Steel Corp, 1988a, JP63207489A Nippon Steel Corp, 1988b), LNG receiving base (Patent No. JP11034971A Ishikawajima Harima Heavy Ind, 1999), LNG tank construction (Patents No. JP10291582A Ishikawajima Harima Heavy Ind, 1988a, JP10291581A Ishikawajima Harima Heavy Ind, 1988b, JP2000249295A Ishikawajima Harima Heavy Ind, 2000), etc. For the USA, the filed patents were aimed at tackling technologies regarding offshore LNG terminals (Patent No. US3766583A Gulf Oil Corp, 1973, US4188157A Ellefsen, 1980). South Korea started patenting activities after 2004, and China's participation was even later, starting from 2010.

The global distribution of patent filings of the above mentioned five countries is illustrated in Fig. 4. It is obvious that the TOP5 patent application countries filed the great majority of their own patent documents in their own patent offices, and only a few were filed under Patent Cooperation Treaty (PCT) through World Intellectual Property Organization. Since patents are territorial, a separate patent needs to be filed in each country where the patent protection is necessary.

4.2. Patent assignees and patent portfolios

Table 1 presents the 10 most active patent assignees in the field of offshore LNG storage and transportation technologies. Data shows that the top three assignees are all Korean-based companies. Daewoo Shipbuilding & Marine Engineering takes the first in patent applications, with its number of applications totaling at 85, followed by Samsung Heavy Industries and Hyundai Heavy Industries. And of the rest 7 listed assignees, three are based in France, two are in China, and USA and Switzerland each has one assignee listed. Besides, only one of the top 10 assignees is a university, which is Dalian University of Technology, based in China.

In order to better understand the technological strength of the patenting countries, IPC codes are adopted to analyze the technological categories involved in offshore LNG storage and transportation (shown in Fig. 5). IPC codes are categorized by alphabets A-H, covering most of the existing technologies. Each capital letter (A-H) are subdivided by its

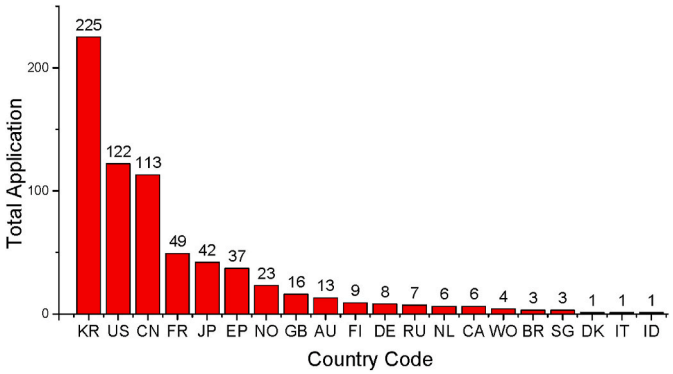

Fig. 2. Total application number of each patenting country.

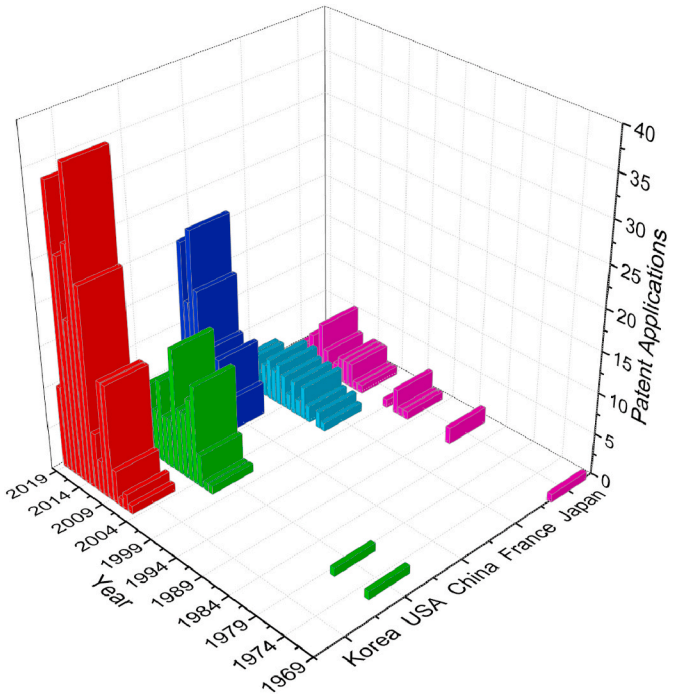

Fig. 3. Yearly patent applications of the most active countries.

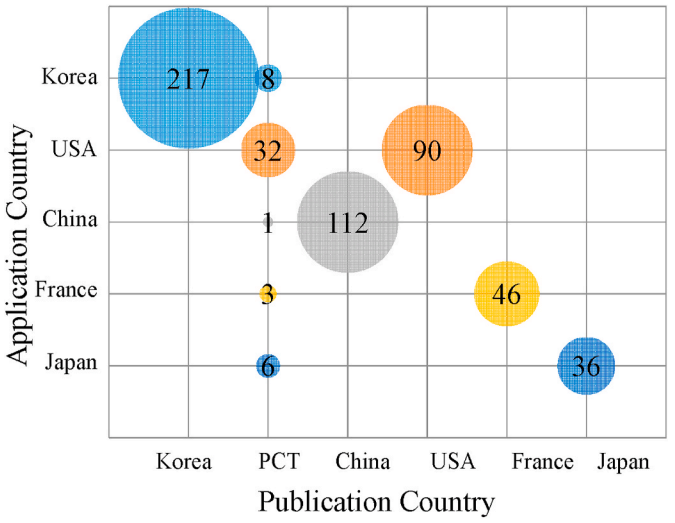

Fig. 4. Global distribution of patent filings.

Table 1
Top 10 assignees of Offshore LNG Storage and Transportation Technologies.

No.	Assignee	Country	Patent Count
1	Daewoo Shipbuilding & Marine Engineering	Korea	85
2	Samsung Heavy Ind	Korea	49
3	Hyundai Heavy Ind Co Ltd	Korea	38
4	Single Buoy Moorings	Switzerland	14
5	China Nat Offshore Oil Corp	China	13
6	Gaztransport Technigaz	France	11
6	Technip France	France	11
8	Exxonmobil	USA	10
8	Univ Dalian Tech	China	10
10	Cryostar	France	9

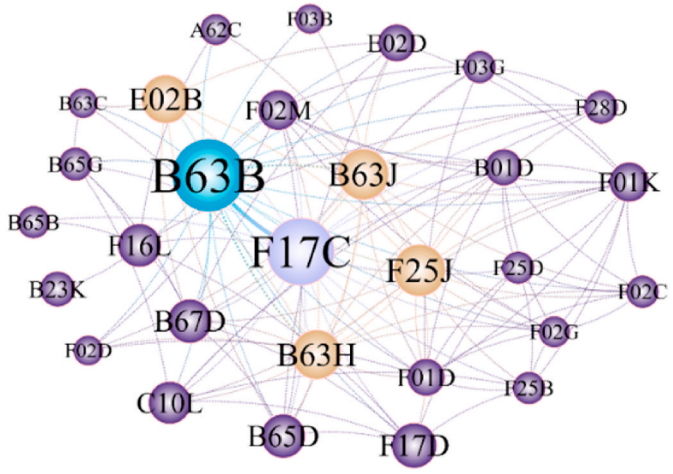

Fig. 5. IPC Subclass co-occurrence.

following figures (IPC classes) and letters (IPC subclasses), in order to cover a more precise technological area. The co-occurrence of IPC codes is due to the fact that a single patent can be categorized into multiple IPC codes. Besides, the top five IPC subclasses are listed in Table 2. It is obvious that the majority of the patents are under the IPC classes of B63 (the section for Ships or Other Waterborne vessels; Related Equipment) and F17 (Storing or Distributing Gases or Liquids). As for the subclasses, B63B ranks the first, covering over half of the total patent documents. F17C takes the second place, with 240 documents being categorized under this subclass.

Patent portfolios of the TOP 10 patent assignees are shown in Fig. 6. The number within a bubble refers to the documents of a patent assignees filed under a certain IPC subclass. The vertical axis lists the TOP 10 patent assignees and the horizontal axis exhibits 10 IPC codes with the largest numbers of patents. All the TOP 10 patent assignees has filed patent documents under B63B. And as for F17C, except for Technip France, all other TOP 10 assignees have filed documents under this category. Samsung Heavy Ind, ranking the second place in its patent numbers, has filed patent documents under all the TOP 10 IPC subclasses, while Daewoo Shipbuilding & Marine Engineering, ranking the first place, does not have patents filed under F16L (Pipes; Joints or fittings for pipes; Supports for pipes, Cables or protective tubing; Means for thermal insulation in general).

4.3. Cluster analysis of key technologies

Clustering is a data mining method used for categorize data items into clusters based on their similarities (Jain et al., 1999). Cluster

Table 2
Top 5 IPC subclasses of offshore LNG storage and transportation technologies.

No.	IPC Subclass	Technological Category	Patent Count	Percentage
1	B63B	Ships or other waterborne vessels; Equipment for shipping	363	52.7%
2	F17C	Vessels for containing or storing compressed, liquefied, or solidified gases; Fixed-capacity gasholders; Filling vessels with, or discharging from vessels, compressed, liquefied, or solidified gases	240	34.8%
3	F25J	Liquefaction, solidification, or separation of gases or gaseous mixtures by pressure and cold treatment	60	8.7%
4	B63J	Auxiliaries on vessels	55	8.0%
5	B63H	Marine propulsion or steering	47	6.8%

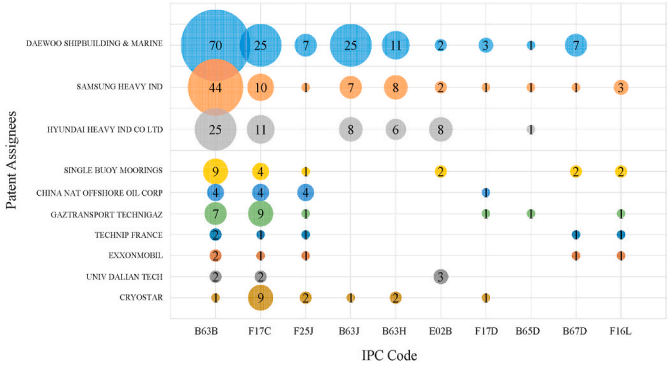

Fig. 6. IPC Patent portfolios of TOP 10 patent assignees.

analysis has also been adopted in patent analysis for clustering patent data according to their relevance (Abbas et al., 2014a,b). The cluster analysis of key technologies based on the retrieved patent documents regarding offshore LNG storage and transportation was conducted through the terminology extraction and term co-occurrence built-in function in *ITGInsight*. The extracted terms were manually screened after the automatic extraction. Altogether five technological topics (clusters of terminologies) were obtained as shown in Fig. 7.

Cluster 1 (Blue): The blue cluster is a selection of terms regarding LNG storage. The biggest node in this cluster is the term "storage tank", which is connected to 43 other terms and appears in 33 patent documents, among which "Marine structure for handling liquefied natural gas has storage tanks supported in cells in a lower concrete section" (Patent No. US4188157A Ellefsen, 1980) and "Cellular tanks for storage of fluid at low temperature" (Patent No. WO2006001711A2 Det Norske Veritas, 2006) have largest number of citing patents, being 58 and 42, respectively. The term "boil-off gas", connecting to 4 other terms and appearing in 8 documents, has a frequency number of 14, ranking the second in this cluster. Boil-off gas, or BOG, is the vapor phase of LNG and may lead to over pressure in the storage tank, causing safety issues (Adom et al., 2010) Patent No. JP2005214313A Eng, 2005 cited by 15 patent documents, proposed a boil-off-gas (BOG) processing system for BOG re-liquefaction. Therefore, the insulation efficiency of storage tanks is one of the major factors that influence BOG rate. Daewoo Shipbuilding & Marine Engineering invented a sealing wall and a thermal insulation wall to prevent heat transfer from the exterior of LNG storage tanks (Patent No. EP2157013A1 Daewoo Shipbuilding and Marine, 2010). This patent document was filed in 2009 and its number of citations reaches to 42.

Cluster 2 (Orange): The orange cluster reflects the technologies related to LNG terminals, for instance, "mooring system", "offloading system", "fluid transfer system", "regasification", "flexible hose", etc. Patent No. US20120037240A1, cited by 6 other patent documents, was filed by Chevron Corporation, 2010, proposed a mooring device which is attached to a vessel for transferring of liquid between the vessel and a receiving structure. Patent No. GB2328196A, filed by Bluewater, 1998, invented a rigid transfer arm for transferring LNG between two structures. This patent was the earliest document about LNG transfer arm in the retrieved dataset, cited by 22 patent documents. For the offloading system, in 2004, SBG Atlantia Sbm Atlantia Inc, 2004 filed a patent (Patent No. US20050061395A1) about a floating structure carrying a regasification unit for offloading LNG from a tanker to an onshore gas distribution station, of which the number of citations is 18.

Cluster 3 (Green): The green cluster centers on heat exchange and cold energy utilization. LNG transported by vessels contains a considerable amount of cold energy which can be utilized before its evaporation (Szargut and Szczygiel, 2009). The term "heat exchanger" appears 27 times in 24 patent documents. A heat exchanger is a vaporization device where LNG absorbs heat and becomes gaseous phase (Afrianto et al., 2014). The most cited patent about heat exchange is "Offshore

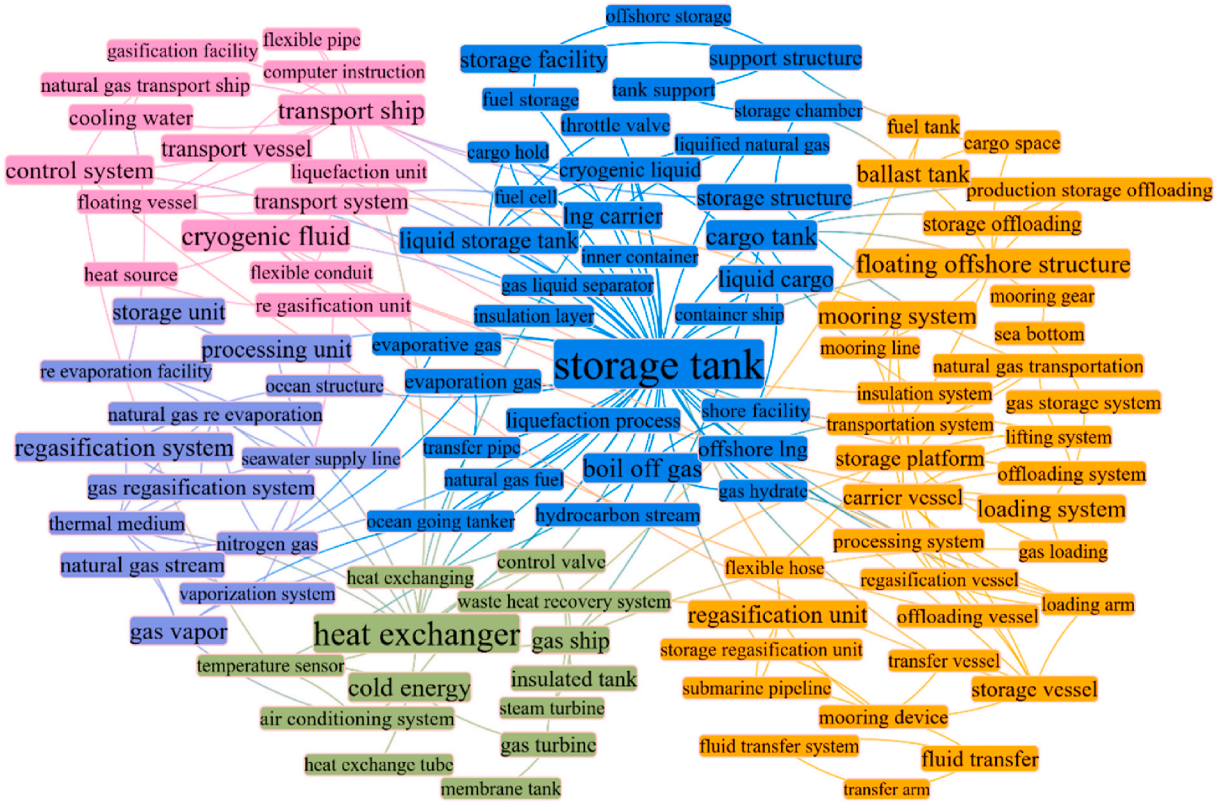

Fig. 7. Co-occurrence and cluster of key terminologies.

heat recovery system" (Patent No. US20080047280A1) filed by BHP Billiton Ltd in 2006. This patent proposed a closed loop heat exchanger where waste heat is utilized to provide warming for LNG. Regarding cold energy utilization, the term "cold energy" appears in 6 patent documents, of which Patent No. CN106762489A filed by Fuzhou University in 2006, invented a power generation system using LNG cold energy.

Cluster 4 (Violet): The violet cluster focuses on LNG regasification. The imported LNG needs to be regasified before it can be delivered to the gas distribution network (Bisen et al., 2018). Regasification is a process to evaporate LNG before the product is ready for distribution (Tomków and Cholewiński, 2015). The most cited patent (Patent No. US20080295526A1 Engineering and Shipbuilding, 2007) in this area is filed by SOFEC in 2007, which disclosed an offshore LNG terminal equipped with a regasification vessel comprising loading arms pivotally

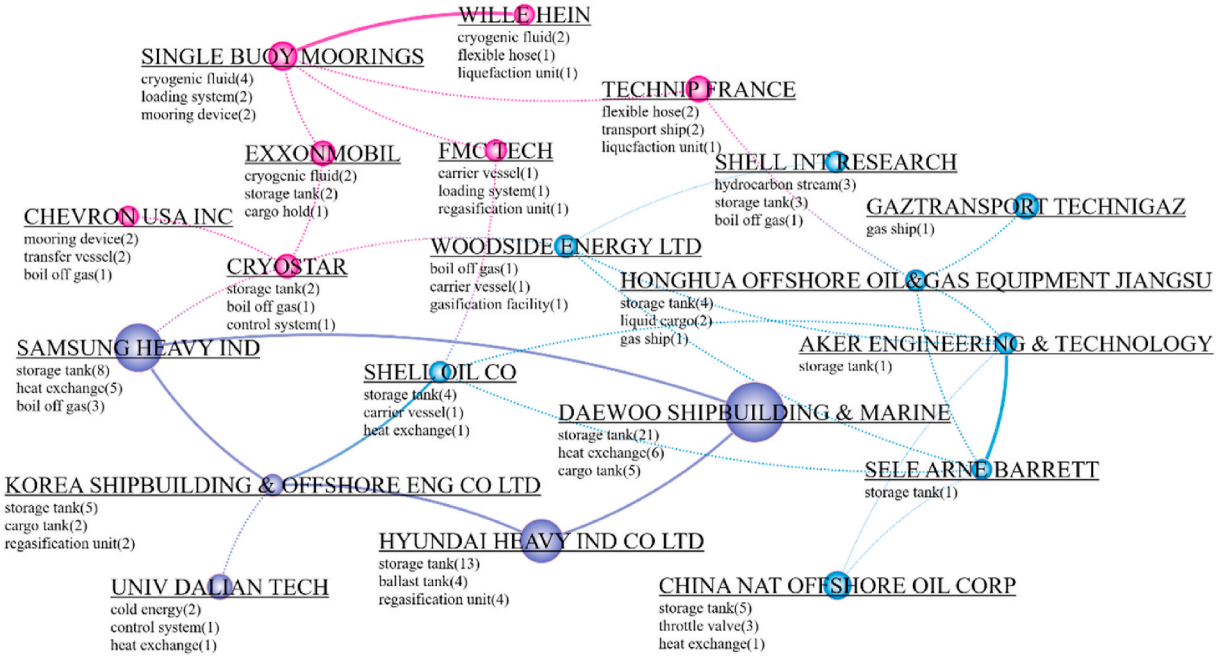

Fig. 8. Correlation of TOP20 patent assignees by terminologies extracted from patents.

coupled to storage vessel in order to unload LNG from the carrier vessel. Another important patent (Patent No. WO2007039480A1) in this cluster is filed by Exmar, 2006, in which a LNG regasification plant and heat recovery methods are proposed.

Cluster 5 (Pink): The pink cluster is about LNG transportation. In this cluster, key terms include "croyogenic fluid", "transport vessel/ship", etc. Since LNG is low-temperature liquid, LNG transportation vessels are equipped with special storage tanks that can resist low temperature damages while at the same time have the ability of thermal insulation. The most cited patent "Vessel for transport of liquefied natural gas" (Patent No. EP2228294a1 Holdings, 2009) is filed in 2009, with its number of citations being 24. This patent document disclosed a vessel for LNG transportation which comprised at least one cryogenic container.

With a closer look at the terminologies extracted from the patent documents, correlation analysis of TOP20 patent assignees by extracted terminologies is illustrated in Fig. 8. The node size is basically in proportion to the number of patents filed by the corresponding assignees, and the line connecting two assignees means that there exist overlaps in the area of technological interests. The thickness of a line also indicates the strength of correlation of the connected two assignees. Terms below an assignee are the top three terms extracted from its patent documents. Since only 100 terms with the highest frequencies are extracted from the retrieved dataset, some assignees only have one term listed. Clearly, Daewoo, Sumsung, Hyundai as well as Shell Oil are strongly correlated with each other, for their overlaps of interests especially in technologies related to storage tanks and heat change. The storage tank is the development focus of most of the TOP20 assignees. Other areas of prioritized technological development include "loading systems" and "mooring device" by Single Buoy Moorings, "throttle valve" by China National Offshore Oil Corporation, "flexible hose" by Technip, "cold energy" by Dalian University of Technology, etc.

5. Conclusion

In this work, past patenting activities in the domain of Offshore LNG Storage and Transportation were reviewed, the most active technological participants were identified, worldwide patent portfolios were constructed, and text mining and clustering of the key technologies were conducted. It is concluded that:

(1) Patenting activities regarding offshore LNG storage and transportation starts in the 1960s;
(2) South Korea filed the largest number of patents, taking up around 1/3 of the global applications;
(3) Top five patenting countries are South Korea, US, China, France and Japan, and the majority of their patents were filed in their own patent offices;
(4) Top three assignees are all Korean-based companies, namely Daewoo Shipbuilding & Marine Engineering, Samsung Heavy Industries and Hyundai Heavy Industries.
(5) Altogether five technological topics were obtained from cluster analysis, including LNG storage, LNG terminal, heat exchange and cold energy utilization, LNG regasification, and LNG transportation.

Results of the present work may serve as a reference for decision makers to formulate strategic plan for potential technological advancements. It is suggested that future work continue to carry out an in-depth organization of the core technologies in the domain of offshore and floating LNG, in order to identify technological opportunities in this area. It is expected that the world-wide systems for transforming scientific research achievements are improved so as to realize a better promotion of new technologies in the area of offshore and floating LNG.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of competing interest

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