Modern Day Pioneering and its Safety in the Floating Ice Offshore

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ABSTRACT

Floating ice offshore pioneering has been performed since the mid 1970s. This paper presents the key lessons learned from 5 such operations of wide geographic as well as operational range. The intent is to present the safety related lessons from these operations for the benefit of the future safety of similar operations.

KEY WORDS: ice offshore operations; station keeping in ice; ice management; safety in ice.

INTRODUCTION

Several early pioneers going to the Arctic went all out, all thinking that they were well prepared, yet some were clearly not prepared for what could happen. Some became heroes while others left their names on pages of history books for not completing their missions, at times paying the ultimate price, losing their lives, equipment and leaving behind a low level, local pollution to the environment. Today the stakes in the Arctic are much higher; consequences of failures can be more global and devastating, especially when they are associated with oil and gas exploration and production.

Modern pioneers are expected to be more responsible and respectful of safe conduct as well as preserving the nature and the future. Rules and regulations are intended to ensure that safety is maintained. Yet, rules for pioneering are very difficult to achieve. Pioneering by nature involves learning new and writing new rules as an integral part of the process of pioneering.

This paper presents the pioneering work performed, the lessons learned as a result, and provides suggestions for how to make future pioneering efforts in the floating stationary ice offshore operations safe. The operations covered are:

- Beaufort Sea moored Drillships
- Kulluk in the Beaufort Sea
- Sakhalin 2, phase 1 DP in ice
- Sakhalin 2, phase 1 oil production, SALM-FSO
- Arctic Coring Expedition, DP in ice

These operations have been reported in several papers including Keinonen and Martin (2010), Keinonen and Martin (2008), Keinonen et al. (2006a), Keinonen et al. (2006b), Keinonen et al. (2000), Pilkington et al. (2006a), Pilkington et al. (2006b), Reed (2006), Tambovsky et al. (2006), Wright (1999), and Wright (2000).

FLOATING STATIONARY OPERATIONS IN PACK ICE OFFSHORE

Beaufort Sea Drillships

When four open water drillships, upgraded to an ice class and winterized, entered the Beaufort Sea mid seventies, together with several ice class supply vessels, the operators had an expectation of having an open water season of a few months each year to be able to explore for oil and gas (Keinonen and Martin, 2010). The operation itself was expected to be a seasonal summer operation only and not to interact with ice.

The first pioneering lesson was that the so-called summer season had significant ice interference. Only highly limited operation was possible without ice interference. To feasibly operate in the Beaufort Sea, the operators realized that the operating season needed to include operating in the presence of ice, which involved significant upgrades to the drillships and the supporting fleet.

Another lesson was that the ice conditions in the region frequently consisted of multi year ice, as well as first year ice with remnants of multi year ice. Since the supply vessels were now finding themselves operating in the presence of thick ice which was beyond their ice class, many of the vessels were experiencing damage to their hulls (dents). This led to the development of two new icebreakers with a much higher icebreaking capability and ice class – the Kigoriak and Robert Lemeur. Figure 1 shows Beaufort Sea drillship operation in ice, eventually having gotten icebreaker support for ice management.

The metocean information available for the Beaufort Sea during the planning and start of the operations in the mid-1970s was scarce. Vessels deployed to the Beaufort Sea were being developed based on a significant wave height that was based on only several years' worth of collected data. Within 1 year of operating in the Beaufort, the 100-year design condition was exceeded. Once the new wave spectra were established, the new 100-year wave was also exceeded within a few years. This revealed yet another lesson, that the availability of good environmental data is paramount for operational planning purposes.

The most central station keeping lessons associated with the drillship operations in the Beaufort Sea were:

- A significant degree of operability in ice was achieved by introduction of ice management icebreakers to support the drillships, and an ice alert system to aid decision-making.
- Ice freezes to the hull of the drillship in cold temperatures in the early winter, increasing loads drastically, and results in a "stick and slip" type action.
- Mooring lines penetrating the surface do not work in ice, as ice interacts with them severely.
- Approaching ice at oblique angles and from the side of drillships result in loads significantly higher than those from the bow. Vaning, orienting the bow of the drillship into ice drift is essential for a stationary vessel in pack ice operations.
- During the early winter, it was learned that excessive ice management actually made things worse. Initially 45cm thick level ice was managed and refroze into 1.2 m thick rubble.

Figure 1. Beaufort Sea late season drilling in ice, November 1979.

Gulf Canada in the Beaufort Sea

Gulf Canada, wiser after over 5 years of operations by Dome Petroleum, designed and built a true first pioneering ice offshore drilling system to perform exploratory drilling in the Beaufort Sea (Wright, 1999; Wright, 2000; Keinonen and Martin, 2010). This included a conical moored drilling platform (Kulluk) and 4 competent icebreakers (Terry Fox, Kalvik, Miscaroo – currently Smit Sakhalin, Ikaluk – currently Smit Sibu) to support the exploration. Their roles included managing ice to enable station keeping, providing anchor handling and towing support, running supplies, etc. The design target to operate the Kulluk independently in 1.2 m thick ice was matched, and significantly exceeded when supported by the icebreakers (Wright, 1999; Wright, 2000).

The key pioneering lessons learned were:

- This platform design for ice was limited in its ability to operate in waves
- The operational limit of the system was exceeded when ice management vessels could no longer break approaching ice. This occurred once, resulting in the platform being pushed off location. This was a result of error in human judgment, as the ice management and alerting system was not fully trained through the operational organization (Keinonen and Martin, 2010).

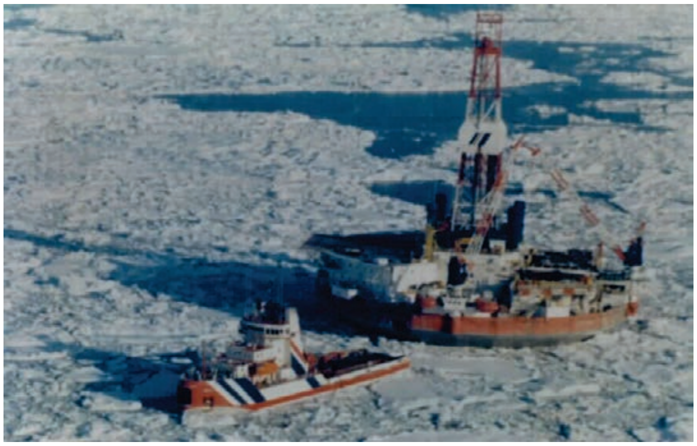

Figure 2. Kulluk and Ikaluk, (photo courtesy Brian Wright)

Sakhalin 2, CSO Constructor Underwater Construction

In May-June 1999, the dynamically positioned construction vessel CSO Constructor performed an underwater construction and inspection operation in the Sakhalin offshore during the thickest ice of the season (Keinonen, 2000; Keinonen and Martin, 2010). This was required to ensure timely completion of the subsea installation work and enable first oil to commence on schedule in July. Figure 3 shows this operation. This was a genuine pioneering operation in several ways:

- The first dynamically positioned operation in significant pack ice (thick first year ice).
- The operation was planned based on past track records of ice seasons in Sakhalin, and the Beaufort sea ice management experience.
- The ice operation was managed and coordinated by a master mariner, a naval architect and an ice expert, all with many years of experience in ice offshore, supported by a Russian ice observer.
- Operational envelopes were tested and expanded based on in field verification of the actual ice loads on the DP system, accepting increases to operational envelopes when evidence in real life confirmed this to be safe and feasible.

Figure 3. CSO Constructor operation in Sakhalin with Smit Sakhalin (Miscaroo) managing 1.3 m ice.

The key pioneering lessons were:

- The station keeping limits of the CSO Constructor were only exceeded when the supporting icebreakers slowed down by ice to below about 4 knots ice management speed, i.e. unable to manage the ice fast enough to keep up with ice drift.
- Open water DP system design does not respond to ice – it only responds to an offset from target position in a delayed fashion, whereas ice loads increase rapidly. As a result the automatic DP vessel operation was significantly less capable in ice than anticipated.
- Orienting the CSO Constructor's bow directly into the ice drift was essential. To achieve this, actual ice drift direction was important to know and forecast accurately at all times for station keeping and for ice management planning purposes.
- Operations in the wake of the Molikpaq were assumed to be easier due to protection from ice. However, this operation turned out to be more difficult than operating in the middle of the moving ice field.
- The station keeping in ice was stopped not because of station keeping load limits being exceeded, but because of ice entering bow thrusters and moonpools.

Sakhalin 2, Phase 1 Oil Production

This oil production was a true pioneering operation. It was the first offshore oil produced in ice using a floating system as an integral part of it. A SALM buoy and FSO moored to it, for oil storage and offloading were an early production stage for Sakhalin 2 large scale oil and gas production, (Reed, 2006; Keinonen, 2006b; Keinonen and Martin, 2008; Keinonen and Martin, 2010; Pilkington et al., 2006a; Tambovsky et al., 2006). The lowest ice class, D0 was provided for the FSO Okha. The oil hose connection at the SALM was a critical ice sensitive item. Oil production was targeted in open water, so no ice management system was designed nor provided. The FSO was taken out of the Okhotsk Sea for the winter to southern regions and the SALM was laid down to the ocean floor. Figure 4 shows the Sakhalin oil production in the late season.

The key ice related pioneering lessons for this project were:

- The season for oil production without ice interference was significantly shorter than anticipated. Forecasting with accuracy and confidence when the ice-free season will start and end was initially not possible.
- An ice management team supported the yearly decisions to mobilize as well as to start oil production (early season), as well as every fall the ending of the season (late season). Extensive ice intelligence, forecasting and ice management resulted in a significant amount of additional operational time and oil production. Annually an average of about a month of additional operational time was achieved through use of physical ice management and ice risk management (Keinonen and Martin, 2008).
- The actual limit to operations was reached in the spring, when it was clear that the ice management vessels could no longer break the approaching ice and clear it sufficiently for the safety of the operation. In the fall it was the increasing ice thickness and repetitive storms, both equally likely to stop the season. In the spring season, ice clearing was possible in up to 8 tenths of ice and in fall oil production in up to 30 cm ice thickness was achieved.
- Malysh (an aluminium line handling boat) had significantly lower ice limits than the rest of the system - 10 cm ice versus 30 cm. This set direct conditional limits to the operations well below the limits of the rest of the system, when the Malysh needed to be used, such as when laying down the SALM.

Figure 4. Oil production in Sakhalin, using SALM and FSO Okha for oil storage and offloading (photo courtesy Sergei Pokrashenko).

Arctic Coring Expedition

This coring operation was unlike any other operation before it. Station keeping was performed in the central polar pack, in thick, mostly old ice (2.5 – 3 m average), including multi year ridges up to well over 10 m in thickness (Keinonen et al., 2006a, Keinonen and Martin, 2010). It used the Russian nuclear polar icebreaker Sovetksiy Soyuz and the Swedish high polar class icebreaker Oden for ice management and Vidar Viking, an offshore support vessel and icebreaker, as the coring vessel. The key ice related pioneering in this operation was the unusual situation where succeeding in the coring was a historical landmark. Losing position would have only resulted in the need to use an available full set of spare riser, etc. This became a safe opportunity to use all possible vessel operator skill and to learn the physical limits of the operability of this system. Figure 5 shows the ACEX coring and station keeping operation taking place.

The acceptable failure of staying on location allowed the vessel operators to use their skills to the best degree possible. This became a powerful demonstration of the physical limits of the ice management vessels and the station keeping operation.

Figure 5. Vidar Viking station keeping in ACEX, with Sovetskiy Soyuz managing ice, Oden in foreground.

The key pioneering lessons based on the ACEX operation were:

- Automatic DP was not possible in severe ice, due to the vertical sides on the stationary vessel. Rather, the main thrusters and rudders of the Vidar Viking were operated manually to maintain position and heading.
- In high concentrations of severe ice, it was difficult to orient the Vidar Viking into the ice drift and impossible to turn the vessel around to follow a drift loop. The vessel was kept within the allowable offset by using the ice management icebreakers to release the ice pressure around the Vidar Viking.
- Within the relatively large allowable offset of 50 m, the Vidar Viking was able to ram and split approaching floes which otherwise might have challenged its station keeping.

Summary of Key Lessons

Performing an ice offshore operation with a stationary floating platform is one of the most complex marine operations, using multiple vessels to manage ice in close proximity to one another in moving pack ice. The need to know how severe the ice is on arrival at the stationary platform, for operational decision-making purposes, puts major demands on the support system. Several factors have been common to most or all such pioneering operations:

- Keen operator desire to operate in as much ice as was safely feasible.
- All operations used ice management support. Operations stopped only when icebreakers stopped being able to continue to manage the ice to target standard.
- All stationary floating platforms were operated in ice thicknesses significantly exceeding their expected operational capability as well as beyond their ice class.
- All the stationary platforms had an ice class.
- None of the platforms, except for the Kulluk, were designed for station keeping in ice.
- The pioneering operations have all been operated using experienced individuals in key positions. The initial Beaufort Sea operation which started from the first principles, was the first true ice offshore pioneer project.
- Most of the preset operational and safety limits were adjusted based on what was learned and documented in the field during the operation. Most adjustments were upwards in terms of ice operability.

In some operations, weak links in the system limited an otherwise higher capable system, for example: Malysh for Sakhalin oil production, ice getting to bow thrusters and moonpools on CSO Constructor, vertical sides of Vidar Viking limited its ability to turn.

It has also been observed that the ice management system itself gets significantly scrutinized. The credibility of the ice management team and its actions depend on continuously accurate assessments of the situation. In ice offshore the operators start to put less attention to ice management teams actions in the two extreme cases:

- When the bad forecasts do not seem to ever come true
- When ice management is performing a perfect job and leaves little to be desired

In the first instance, operators tend to ignore the indicated risks leading to compromises in the safety of the system. In the latter case, operators can trust the risks indicated by the ice management team, which is the genuine target. when operators stop being interested about the ice management, it is absolutely essential to be able to tell which is the case.

"KILLER" EVENTS AND CHAINS OF EVENTS

The identification of such dynamic events that have a risk of causing severe consequences if not appropriately recognized in advance differ from those in ice free operations. In moving pack ice, it is not possible to simply stop an operation and stand by and wait through a storm event. This would potentially cause significant ice pressure or bring in ice to the site that is beyond operable. This type of triggering occurrence of non-operable conditions is here called a "killer" event, as it has a potential to cause severe consequences.

The forecast of occurrence and timing of storms and their intensity has turned out to be difficult from time to time in new regions. The tracking of the low pressure system across the operational area can produce a wide range of types of events from an operational severity perspective.

The events that have been experienced in the reviewed pioneering operations with a potential to become a killer event are:

- Ice River – a tongue of ice approaching much faster than forecasted
- Major waves/swell – limiting/stopping all operations
- Ice pressure – increases severity of any ice condition rapidly and significantly
- Icing – compromising access to and operation of equipment, clearing of icing delays operation
- Ice in waves/swell – managing ice is difficult in waves/swell, as ice may interact with the hull of an icebreaker in areas above and/or below the ice strengthened regions.
- Early occurrence of storms has resulted in a) the inability to operate delays reaction time allowing ice within the t-time, and/or b) the suspension of an operation
- Severe storms stops all operations, since it can encourage severe ice to approach the site closer than acceptable
- A mistracked storm system may result in the occurrence of ice pressure as a consequence of wind direction being virtually opposite to what has been forecast depending on which side of operation the low pressure passes.

The above dynamic events are relatively straightforward to identify once they are detected and one knows what to look for. This requires that the data recording cover a sufficiently large geographic area. Yet, two factors with each event are essential to understand in order to develop an approach that can genuinely take care of the safety of a floating stationary operation in ice. These are:

- Triggers of events need to be understood, and those triggers need to be forecasted.
- Consequences of single events are typically straightforward to assess, but it is important to be able to assess the possibility of triggering a sequence of events. A sequence of events can lead to increasingly severe consequences, unknowns and highest risks.

An example of a triggering event is an ice dam breakup at River Amur estuary (Tambovsky et al., 2006). This resulted in severe large ice floes from ice kitchen NW of Sakhalin to be sent around the top of Sakhalin Island to the NE coast, approaching the operational site rapidly. The fresh water surface current split the whole offshore icepack along the NE Sakhalin area (Figure 6) and pushed the severe ice through to the operational area whilst the rest of the offshore ice pack was drifting only a fraction of the speed of this fresh water and ice river. The ice

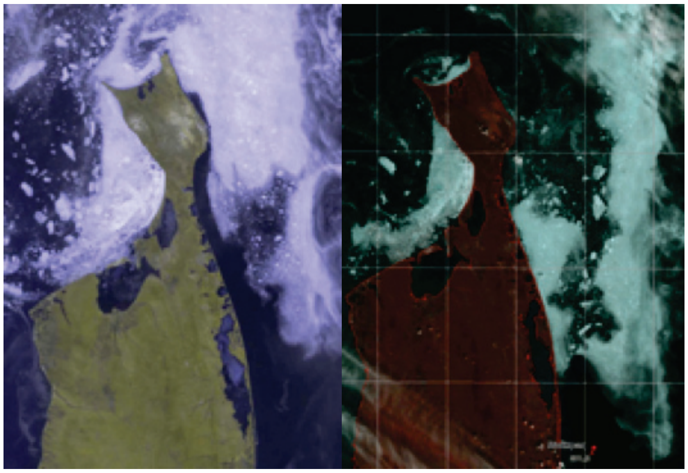

Figure 6. Ice invasion of ice kitchen ice resulting from Amur River Breakup, May 20 (image on left) – 27 (image on right), to Sakhalin East Coast, Tambovsky (2006).

that was brought to the East Coast with this ice river tongue progressed at about 20 nm per day. At the same time as can be seen in Figure 6, the offshore pack along the east coast moved about 30 nm south, or 4.5 nm per day. Once this event was identified, it resulted in a standard procedure to annually follow and forecast the breakup of Amur River ice dam, and track any potentially major surface current of river water and ice with it to the operational region.

Icing is an example of a triggering event as well. It causes a need to clear ice from the equipment. This will result in a delay in whatever operation may need to take place. The time to remove the ice and enabling the continued operation of equipment is difficult to forecast, as it varies with the severity of the icing event and the weather and swell following the icing event. Major icing events happen prior to formation of sea ice and are associated with a combination of cold temperature and storm winds, as shown in Figure 7.

Tracking the possibility of the above types of identified events at acceptable levels is one of the keys to a consciously safe pioneering operation.

HOW TO PIONEER IN ICE OFFSHORE

The following have been the key ingredients of a successful pioneering operation in pack ice with a floating system, based on the track record of the listed previous operations.

Get the Seasons Right

For each operation, the operators had collected information related to ice, oceanographic and climate data from the operational region. In some projects there were even upward looking sonar deployed to collect an underwater ice profile as well as ice drift for the whole winter, or more than one winter. Satellite images were collected to show the spatial distribution of ice as a function of time. The extensive quantity of ice maps and other environmental information provided a confident feeling in advance that it was understood what kinds of conditions would be expected. Yet, the experience suggests that such data has not been of consistently high quality. For example the wave statistics in the Beaufort Sea resulted in the exceedence of the expected 100-year wave after only the first year.

For oil exploration, or other seasonal operation that is in principle possible to perform in ice-free conditions, it is wise to specifically evaluate what the actual season will be for an ice-free system operation. Two of the pioneering operations in this paper were intended as ice-free

Figure 7. Icing on SALM after a storm, prior to formation of sea ice. Ice being cleared from the ladder to the SALM, in a snow storm from Malysh, using a mallet (photo courtesy SEICL).

summer operations. It turned out that the actual season length in ice-free conditions was much shorter (Sakhalin2, Phase 1 oil production, and oil exploration in the Beaufort Sea with drillships) than expected based on the ice data available prior to the operation and also in one case (Beaufort Sea drillships) interrupted by ice invasions. The actual pioneering seasons illustrated in Figure 8 are typically:

- Confirmed ice free season – no ice present
- Open water season – typically ice free but with possible presence of some ice or at the start of winter cold temperature
- Early season – with remnants of thick melting ice present
- Icing season – with cold temperature and high winds
- Late season – starting with formation of first ice
- Winter season – covering the full winter, up to year round

The time of ice melting and clearing from the operational site was initially difficult to predict for any spring for the Sakhalin offshore area. The possible range of ice clearing dates was very wide. Earliest start of clearing of ice could be late May and the latest some time late in July, even historically ice had been present along Sakhalin east coast into August.

The late season started with a stormy season followed by a cold spell from mid to late October, resulting in first ice between mid November to mid December.

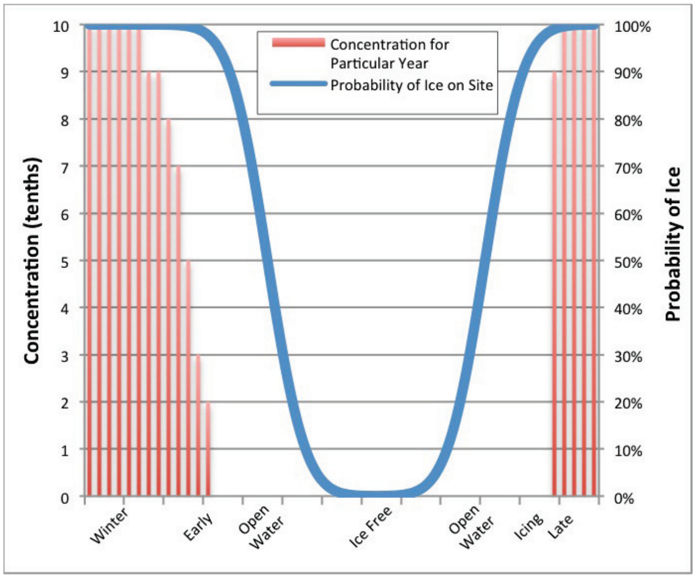

Figure 8. Seasons of operation with various degrees of influence of ice on the operability.

The experience with the intended open water seasons suggest that being prepared for ice free operation only highly limits the available season length, for two reasons:

- First the season may not be as long as is planned or expected, as ice invasions and cold temperature interrupt this.
- Secondly if equipment is specifically designed for ice-free operation only, any need to operate in ice for whatever reason is not possible, or severely limited.

If there is any chance at all that the operation needs to continue when ice is in the region or the operation may need to continue into cold temperatures, building at least to an ice class will significantly increase the operational seasons available. Furthermore, if there is any chance that a season can extend beyond the ice free, it is essential to incorporate ice management into the original planning.

Ice and Environment Forecasting

The historical ice and environmental data is important and carries a significant reference value in a supporting role to real life data. It provides good statistical reference and helps establish what other years have been like. However, when arriving in the field the extensive background data itself was initially of little interest and it was more important to collect satellite images, perform ice reconnaissance, etc. to map what the ice conditions actually were prior to the start of and through the operations. Yet even this together with specific, regularly collected real time data and information of all relevant ice, oceanographic and weather parameters during the operation form only the basic starting point for operational planning and decision-making.

For ice risk evaluations, operational decision-making, and ice management planning purposes, the following types of environmental parameters may need to be recorded real time and also forecasted:

- Icing
- First formation of ice
- Start of stable ice growth
- Ice thickness, deformation etc.
- Decay of ice
- Ice drift (speed, direction, changes of drift)

Figure 9. Kigoriak, escorting Explorer III through about 2 m thick land fast ice though channel prepared for this. Suppliers 4 and 7 following.

- Changes in ice concentration
- Ice pressure
- Wind
- Waves/swell
- Current
- Fog
- Snow cover, precipitation
- Temperature (air and water)
- Approach of major ice obstacles

The actual list of which are relevant depends on the type of operation targeted, sensitivity of stationary vessel to ice, and the ice environment in the area/region in question.

An approximate probabilistic approach is ideally needed. Such development has been initiated based on prior pioneering experience and data, yet such can only be calibrated on site, integrally as a part of operational pioneering in any given project and operation. At the pioneering stages such an approach includes a degree of expert judgment until the operation has matured enough that all possible events have been witnessed and incorporated into routine forecasting. The pioneering stage for such forecasts has been in the order of 3 – 5 years. Typically the basic operation itself is learned and calibrated to routine relatively fast. Learning to know the environment and the full range of dynamic events takes more time. Learning to respond to the new events is learned as these events happen, utilizing judgment of the key experts to ensure safety while learning. The calibration of actual operability may take a longer time in areas where the ice conditions vary significantly from year to year. Sufficient number and variety of ice events are needed for good calibration of the ice management operation itself.

The local dynamic phenomena were not well understood prior to the operation despite having extensively studied the environment in all the pioneering operations considered here. Kulluk operation was partially an exception, as it started from the lessons learned from the first 6 years of operations in the Beaufort Sea.

One of the biggest challenges during the pioneering operations has been the ice drift forecast. It is relatively easy to develop an ice drift forecast that provides satisfactory results most of the time. However, the time of change and the exact type and quantity of change in the ice drift is significantly more difficult to forecast. Important lessons contributing to ice drift forecasting were:

1. Normal weather and ice drift forecasting is not sufficient for a sensitive floating ice offshore operation such as oil production in ice. The questions that need to be asked from the forecasters are changing to probability distributions of events, for example:

- Occurrence of a wind (ice) event
- Time of start of event
- Duration of event
- Strength of event
- Direction of event

2. Similarly the currents, especially local current events need to be forecast as input to ice drift forecast. Forecasting currents locally has been compromised by the fact that continuous measurement of current was not performed during these operations. Typically only sporadic current measurements were taken during the ice offshore operations considered.

3. The use of calculated tidal currents as a basis for ice drift forecast ignores most local phenomena including rapid current in the ocean, resulting in the so called “ice river”.

The Role of T-time

Operations with a short t-time with a possibility to stop the operations practically instantly are the easiest as it is possible to only respond to what is actually happening in real time. The longer the t-time the higher the probability to have stop operations as a precaution for ill defined events with low probability of arriving to the site.

The biggest impediment of floating ice offshore operations has been and is expected to continue to be a long t-time, beyond a few hours. The longer the t-time the stricter the demands for the longer term forecasts of winds, waves and ice drift. Inaccuracy naturally built into forecasting, especially of any changes to environmental events increases risks exponentially with increasing t-time. Forecasting of especially some local/regional phenomena are not possible in early pioneering in a geographic region. One must initially assume that in a new operational region a wide range of events can be present which are not even recognized. This was certainly true for all those regions where the operations referenced in this paper took place. Also, when the t-time extends beyond about one day, no known forecast of events provides low enough probability of unacceptable events on a consistent basis to be able to justify operations with unacceptable consequence resulting from such an event. Only with locally calibrated forecast models is it possible to start to get satisfactory accuracy and dependability of risk assessments to warrant operations such as producing oil or in exploration being in a hydrocarbon zone, when a long t-time is present, especially when the platform has limited ice tolerance relative to actual ice conditions.

The bottom line is that there is a need to operationally respond to a rapidly increasing number of possible events with increasing t-time and understanding the inaccuracies of the forecasts, whereas with a short t-time one can respond to mostly only a few actually occurring events. The down time resulting from a long t-time can disable operations, especially in the pioneering stages. Using a risk based approach forces one to consciously consider all elements of the operation that could potentially lead to risk. Otherwise, decision-making must be performed solely based on experience based judgment, increasing the dependencies on a single individual. Risk based approaches would not be used to substitute expert judgment and experience, but rather provide the most valuable quantitative input information required to support consistent, safe operational decision-making by the experts and/or management. Specifically in Sakhalin oil production, both the oil operator and the SALM/FSO operator stated the need for a risk based operational decision making, as they would not accept unknown risks being taken in such a sensitive operation.

The driving force behind the development of risk based ice management was associated for the long t-time associated with Sakhalin oil production operations – typically 36 hours. It was not the desire to understand risk but the realization that a long t-time based fool proof operation resulted consistently long time periods of no events and no operation. It was recognized that in order to fully identify and to take advantage of the available operational windows, the following was required:

- Understand all ice risks specifically at all times
- Increase of layers of contingency for competent response
- There is a need to err on the safe side because of failure being highly unacceptable and the operation being of pioneering nature, containing surprises

If one uses high quality local experts who already understand the environment, the pioneering still takes place, even though learning can be significantly faster. It was discovered in Sakhalin ice offshore that the local experts already knew most of the regional and local environmental and ice phenomena. The most important new requirement was to start to ask the right questions to those experts. The common factor was that the basic data that is generally considered describing ice and environmental parameters need to be significantly enhanced to match the actual needs for each specific operation, platform, etc. The basic need is to forecast everything about the ice and environment that changes and can have an influence on the efficiency and/or safety of the operation.

Understanding Station Keeping Operations

For all pioneering operations, the operations were pre planned. However, it turned out that the operations in the presence of ice were not well understood. The learning of the operation took place mostly only during the actual operation. The basic ice management techniques had been learned in the Beaufort Sea when the moored drillships were used. All the rest of the pioneering operations listed in this paper used and built onto ice management based on strategies and techniques learned and tested in the earlier operations already performed.

One key factor in stationary floating operations in ice is the fact that each platform behaves differently in significant changes of ice drift. The differences between platforms in their response characteristics put significantly different requirements to the station keeping as well as ice management operations to enable the vaning in curved ice drift but especially in ice drift reversal situations:

- Beaufort Drillship – moored, practically fixed orientation
- Kulluk – fully symmetric thus no need to alter orientation
- CSO Constructor – only changed heading as ordered by operator
- SALM-FSO – vanes readily in response to combined environmental forces. Highly complex dynamic response of the SALM – mooring Hawser – FSO having each own dynamic characteristics, as well as different responses to the environmental loads (wind/current/ice/waves) which all could arrive from different directions.
- Vidar Viking – manually operated and oriented as ordered by operator - hard to turn in thick high concentration ice

These pioneering operations experienced limited down time due to an unacceptable station keeping load; only a small fraction of these interruptions were based on the forecast or actual exceedence of global load on stationary platform (Keinonen and Martin, 2010, summarize the basic platform capabilities in ice). The full range of scenarios that have challenged station keeping and in most occasions actually led to downtime are:

- Ice entering bow thrusters, resulting vibration and loss of thrust for DP.
- Ice entering moonpool(s)
- DP vessel unable to orient itself into ice drift – Specifically the Vidar Viking, resulting in near loss of allowable offset by being pushed sideways
- Ice management vessel drifting with ice pressure onto stationary vessel (Beaufort Sea drillship)
- Exceeding set station keeping limits, being pushed off location (Kulluk)

Ice Management in Support of Station Keeping

The physical ice management operations that supported each of the operations have been highly complex and individually unique. These contain more pioneering than any other component of the stationary operations, as the requirements and strategies for ice management has drastically varied from one operation to another.

All pioneering operations depended on the performance of physical ice management. All of them used mainly traditional ice management strategies and techniques, which included mostly:

- Reduction of floe size by breaking incoming ice floes down in size
- Creating a large amount of brash ice allowing ice floes to move around the platform due to the compliant matrix of brash
- Pushing large ice floes off the drift line
- Releasing ice pressure by circling the stationary platform

During Sakhalin 2, Phase 1, there were two additional ice management methods developed and used in support of the operation:

- Pre ice management
- Azimuth ice clearing

Pre ice management is the process of managing severe ice features that may arrive to the site, but are not directly forecasted to do so. By managing these features far updrift from the operational site, it provides ample time to further manage them should they drift towards the operation. The pre ice management strategy was successfully executed, to eliminate large unmanageable floes from approaching ice fields in the whole NW Sakhalin offshore region.

Azimuth ice management was incorporated into the ice management system and proved particularly useful during the early season for clearing floe ice. By remaining stationary up drift and orienting the propeller wake outboard, it was possible to deviate ice away from SALM and FSO. Not only did this raise the overall operability from approximately 2/10ths to 8/10ths concentration, it also enabled the ability to perform oil export in near 8/10ths concentration by keeping ice from collecting in the export hose.

While the azimuth ice management vessels could achieve highly efficient ice clearing, the introduction of azimuth ice clearing has been a significant challenge. Achieving such efficiency has been compromised by:

- Complexity and lack of ergonomics of the manual controls for their DP system
- Lack of pre programmed modes of ice clearing operation
- High requirements of human skill for such operations resulting in rapid fatigue and reduction in performance

The pioneering ice management operations have been directly dependent on the presence of experienced ice management operators. An expectation has been at least partially built into the operational plans that ice management will be performed efficiently when it is most important. The presence of the experienced operators as ice management masters has justified this. Both their judgment of situations as well as operational skills have resulted in an acceptable reliability, despite of the fact that ice management masters do not actually operate a vessel, but are on board for planning, guiding and training purposes. The regular crew has always operated the ice management vessels.

It has also become evident in operations where severe ice conditions are present for an extended period of time that fatigue becomes a key factor, and it is no longer appropriate to plan highly sensitive operations based on a single ice management master on an ice management vessel 24/7.

THE MOST IMPORTANT LESSONS

It is essential to consider all the above lessons when developing an ice management plan, as these lessons form the foundation that has become an integral ingredient in the successful and safe execution of the pioneering ice offshore projects with floating platforms.

Yet, once the operation starts, some of the most important ingredients of a successful safe execution of the pioneering operation are still missing. The nature of pioneering itself has not changed from the old historical times. The natural part of such pioneering has been experiencing unplanned surprises. The safety can be literally determined by the ability to recognize soonest and to responding in an expedient and appropriate way to such surprises.

One of the keys to safety is to be able to answer the question: when things do not go according to plan and there are surprises, how is safety going to be ensured?

There is plenty of experience where close calls outside of the plan have taken place. Such contains near ship collisions, the alerting level jumping from the green totally safe level directly to the highest black level. This can be a consequence of a variety of things. For example some ice may have slipped through the system undetected, or human judgment has been inaccurate or inappropriate and resulted in an inappropriate response. It can also be a sequence of events that has simply lead from one inoperable situation to another, and not being able to manage the ice in accordance with the plan.

This makes the process of learning by doing as a necessary ingredient of the plan for a pioneering ice offshore operation. It is essential to plan the learning process for this to take place safely. It includes the following set of tools that enable such safe learning:

- Develop a full range of plausible scenarios
- Redundancy
- Use of experienced individuals
- Building “learning by doing” into the plans
- Training

Perhaps the most natural and powerful tool is to plan to learn when a non critical operation is taking place which is possible to stop quickly and the consequence from any failure would be acceptable. This way of learning could be also named field calibration of operability.

Severe Scenarios

When going to a new area it is essential to document what is known of this area and how the environment behaves. It is also equally important to describe the operation to the best ability. In this way it is possible to start to follow whether the conditions and assumptions related to the environment and the operation used when developing the ice management manual are accurate or need modifications. This process allows earliest identification of any possibility of departures from plans and to make it possible to make immediate adjustments based on such departures.

The scenarios of what may go wrong during the operation need to cover an extensive set of the most severe plausible ones. Having these scenarios thought through will focus the thinking and enable active following whether any of such scenarios can potentially start to happen. The scenarios need to be associated with the consequence of failure, and in all cases have an acceptable response developed to such an occurrence.

An example of a severe scenario is the icing of equipment. In the Sakhalin 2, Phase 1 operation the SALM buoy got severely iced, which increased the t-time by more than a day. Figure 7 shows the ice being removed from the frozen buoy in significant snow and wind.

Without these scenarios, the operational personnel will not have an appropriate pioneering preparedness, and can be caught unprepared, unable to identify and respond to such events.

One area that needs to be included in the scenarios is identification of any relevant weak links in the system, which could lower an ice operational limit, such as the need to use a small boat, Malysh in Sakhalin operation (Keinonen and Martin, 2008). The operators of the small craft tend to readily find the actual operational limits in real life operation. The operation of such small vessels amongst thick ice floes does not lend itself to alerting. This is a prime example were experience, caution and prudent practices by marine operators is required.

Ensure Adequate Redundancies

All possible inaccuracies need to be associated with built in contingency and redundancy so that so that the full range of events will be possible to cover in accordance to the plan. These cover mostly the following efficiency reducing inaccuracies and uncertainties:

- Weather, current and ice drift forecast
- Ice data
- Ice detection
- Reduced operational performance (due to inefficient plan, lack of operator skill, fatigue or judgment, or failure of equipment)

The operation requiring the most contingency was the oil production for Sakhalin, where as many as five vessels were used for ice management at the same time, containing two full layers of contingency. This was required to ensure safety in the spring in the presence of severe ice in the operational area. It was thanks to the built in contingencies that oil production was successfully and safely performed in 8/10ths concentration of thick spring ice and the presence of stamukhi within only miles from the operational area, with practically no ice interaction with the SALM/FSO (Keinonen and Martin, 2008; Keinonen and Martin, 2010).

The biggest risk associated with redundancies is that it has turned out that gradually there may be a tendency to start to use the redundancies as part of a normal operational limit. This can create the biggest risks as this approach removes the redundancy. It would be a prudent practice to enforce reporting of any incidents and close calls that have resulted in the use of the added redundancy. For this it needs to be clearly defined where the normal level of operation ends and the use of redundant capability starts.

Use of Key Experts

There is no replacement to the use of key experts with long experience in as similar an operation as possible. This has ensured that any possibility of departure from actual plan and forecasts is anticipated, detected and understood as early as possible. The use of experts further benefits in two other ways:

- Their ability to respond rapidly and in the most appropriate fashion
- The experts in an operation tend to learn the most relevant lessons whilst the new experiences are occurring

The key advances in the ice offshore take place step by step. Without key experts the observations of the operation would start at a very basic level. The first pioneering steps for any newcomer tend to contain the most surprises, as well as can be the riskiest as well as priciest.

Experienced personnel are needed in all areas of an ice offshore operation, as failures can be a result of many types of reasons. At least the following experts provide key operational safety related input:

- Ice management masters/vessel officers – to coordinate ice management as well as to evaluate severity of ice through breaking it.
- Ice, oceanographic and climate experts – to record real life parameters as well as forecast and evaluate ice and environmental conditions and parameters.
- Risk evaluation engineers – to pull it all together and evaluate the ice and environmental conditions in terms of risk to the operation, make risk assessments in support of operational planning and decision-making.
- Operations manager – who understands a wide range of commercial, technical and operational matters as basis for operational planning and decisions.

In existing operations most of the strategies to manage the approaching ice have been developed in the field operation. Generalized ideas and schematics work as an initial starting point, but each operation has had own specific requirements and restrictions for example related to:

- How close to stationary platform was the ice management operation allowed, as a function of speed of passage of ice management vessel and ice conditions.
- What vessel maneuvers were acceptable close to stationary platform, not to cause increased loads on platform.
- How to eliminate ice being pushed or directed towards the platform with a potential of going under it.

Most learnings have been safe. Yet there have also been close calls that have been handled by highly qualified experts and remained safe. There have only been rare occasions where operational limits have been exceeded. The fact that these have also resulted in only acceptable consequences appears to be largely thanks to the highly qualified experts, and most of all using a precautionary approach to operations, allowing new learnings to take place only in situations with acceptable consequences.

This does in no way prove that future operations will be safe. As soon as the operations will start to take place without suitable and sufficient key experts, the consequence of this would be most likely significant increase of risk, directly as a result of lack of experience.

Influence of Human Factor on Pioneering

The human factors have been all along in a central role of ensuring safety of ice offshore operations, as well as causing risks. The influence of the human will never be possible to eliminate completely. Today, it is difficult to even eliminate a significant portion of it, as the ice management contains several components that are not automated. The ice observations themselves, forecasting, planning operational strategy and tactics and execution of these all contain significant influences of human factors. The real life efficiency of ice management is a direct result of the available performance of equipment, reduced by human judgment and performance.

As the ice itself does not change the human behavior and how the various aspects of human performance influence the operations, it is suffice to raise within this paper only those key points that have been observed in the ice offshore that have resulted in significant contribution to risk:

- Judgment
- Skill - Fatigue
- Ergonomic factors
- Communication
- Operational culture

Key experts in physical ice management have shown systematically the best judgment in planning and executing the physical ice management. The concept of Ice Management Master has worked well.

The requirements of operational skill were raised far beyond the typical mariner required levels as a consequence of introduction of azimuth thruster icebreakers. A significant increase in maneuverability was achieved and also ice management capability using the wake of thrusters. Yet, the complexity of the operation itself turned out to require a significant amount of training.

The required high skill combined with long need to concentrate resulted in reduced performance due to fatigue.

As the control systems used have not been designed for the highly skilled accurate operation it also turned out that the lack of ergonomics resulted time and time again in the inability to perform a required ice management duty without an occasional failure.

The most common risk in all operations has been the lack of a robust communication system which can reliably transmit both verbal and data communication between all vessels and offices participating in the operation. This has at least partially been influenced by the remoteness of the regions from suitable communicant infrastructure, where operations have taken place.

Procedures for communication were not developed to a standard for the ice offshore pioneering. The consequence has been that from time to time miscommunication has occurred which led to execution of different ice management from what was planned, as well as managing altogether different ice than intended.

Operational culture from the traditional use of helmsman does not work well for ice management. The long lag and any inaccuracy in execution of a specific ice management maneuver by a helmsman has resulted some most interesting highly approximate and not efficient ice management maneuvers.

CONCLUSION

Having lived through significant ice offshore pioneering and having seen surprises and a variety of incidents, has lead to the conclusion that the nature of humans or pioneering has not changed from the early arctic explorers and their expeditions. Pioneering inherently contains surprises and risks, a fact that needs to be accepted and handled with utmost caution.

The motivating factor for writing this paper has been to provide a meaningful contribution to the safety of future ice offshore operations, by providing lessons learned. This was achieved to the degree possible within the constraints of the data and information owned by the offshore operators. Regrettably, much of the safety related information is currently held by each operator, not available for the common good, despite of the fact that withholding such information can reduce the safety of similar future operations. The most valuable contribution to future safety, beyond suggestions in this paper, would be for each ice offshore operator to release such ice offshore operational information and data that would enable extraction and analysis of the safety related lessons.

The challenge for regulators is to ensure that the operational safety is monitored and documented. This challenge can only meaningfully be met as soon as the actual operational safety information is available. The regulatory agencies also need to adjust to the nature of pioneering, to enable the true learning that is required to be able to shift the general guidelines to more concrete safety requirements.

The desire to deal with prevention has been in place for a long time, yet the fact that this is a pioneering industry has made the work of regulatory bodies compromised, lagging what happens in real life due to the lack of genuine, specific input related to real life safety and safety challenges of the operations.

Incorporating all safety related lessons and information from all operations is a small task in comparison to what has been spent in dealing with disaster mitigation. Yet, prevention is by far the most efficient and least expensive remedy, and would be expected to carry the highest endorsement by the stakeholders and general public.

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