Minimizing the Impacts of Fishing on the Environment through Innovations in Technologies and Operations

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Fishing operations could create certain impacts on the environment, especially on the fishery resources and their habitats, where the impacts on the fishery resources could be from fishing practices without appropriate fisheries management to control fishing capacity as well as from IUU fishing. Fishing activities could also result in changes of the environment due to carbon emissions, and one of the major concerns is related to the impacts of fishing vessels and fishing gears on fish and non-fish species, incidental catch/bycatch of very small fishes, juveniles, or even the endangered species. Modifications of such fishing vessels and gear, and improvement of the associated fishing operations and practices could reduce the impacts of fishing on the environment. Concerned about the impacts of fishing on the environment, the ASEAN Member States (AMSs) had always been of the consensus on the need to obtain understanding and mitigate the impacts of fishing on the fishery resources and the environment. Given such a backdrop, SEAFDEC and the ASEAN made sure that the Resolution and Plan of Action on Sustainable Fisheries for Food Security for the ASEAN Region Towards 2030 adopted by SEAFDEC and the ASEAN, include provisions on the need to "*Support the efforts to promote low carbon development technologies by minimizing the contribution of the fisheries sector to greenhouse gas emissions, with emphasis on promoting the use of energy-efficient equipment and alternative energy sources*" (Resolution No. 9); "*Enhance the efficient use of energy by adapting appropriate technologies for fishing gear and fishing vessel design, and fishing operations; and promote the use of alternative energy sources" (Plan of Action No. 18); "Improve the capability of fishing crew and workers in fishing industry, and conduct educational and skills development program for new crew members and workers entering the industry; while also adopt appropriate technologies to optimize number of crew onboard fishing vessels*" (Plan of Action No. 19).

Over the decades, SEAFDEC in collaboration with the AMSs has been carrying out activities that address the issues and concerns on the impacts of fishing operations on the environment through responsible fishing operations. Specifically, SEAFDEC/TD with support from the Japanese Trust Fund (JTF) has been implementing the Project "Responsible Fishing Technologies and Practices" that includes activities related to marine engineering technologies (*i.e.*, fuel efficiency, and greenhouse gas reduction, and safety of fishing operations at sea); and on the development of fish handling techniques onboard fishing vessels. Moreover, R&D on the development of appropriate technologies to reduce carbon emissions to the environment in response to the issues of global crisis by climate change, and reduce labor onboard by applying appropriate hauling devices to improve the national economies and fishers' well-being onboard fishing vessels, have also been enhanced.

During the Online Meeting on Reducing Negative Impact to Ecosystem, Optimizing Energy and Fuel Consumption, and Enhancing Safety in Fishing Practices in Southeast Asia, convened by SEAFDEC in September 2020, some technical measures had been suggested to mitigate the impacts of fishing on the environment. These included: closing the most sensitive areas for certain fishing (*e.g.* coral reefs, seagrass beds, nursery grounds); fishing where the fish is (*i.e.* increase fishing efficiency and reduce fishing time); modifying fishing vessels and their operating methods; replacing intrusive fishing gears with the more habitat-friendly gears.

Energy efficiency and fuel-saving options for fishing vessels

All movements of a fishing vessel in the water create resistance force, as the vessel is subjected to dynamic force and resistance of its surroundings to maintain its moving speed. In propulsion systems, the thrust force produced must be equal to the resistance force in order to move forward, and to minimize drag, the vessel's propulsion system should be improved (**Figure 1**). Minimizing the shaft angle could result in reduced thrust variation on the propeller (cavitation) and significantly increased the life span of the propeller.

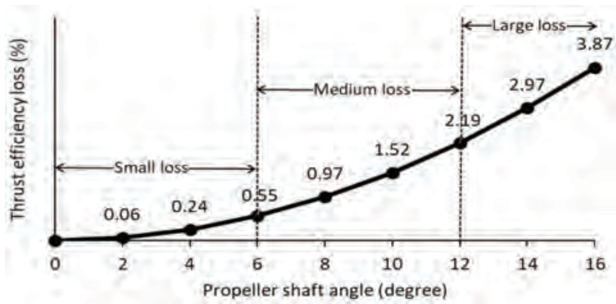


Figure 1. Thrust efficiency loss (%) in relation to propeller shaft angle (degree)

Reducing the propeller shaft angle also minimizes power loss in the transmission system as the upper blade is receding from the onrushing water as it rotates up. When the lower blade is moving forward into the slipstream as it rotates down, it could cause uneven blade loading that creates vibration and/or cavitation.

Vessel design, size of the propeller, propeller clearance, and the water flow's path to the propeller blade should be taken into consideration when constructing and/or renovating fishing vessels to improve the performance and energy use of the vessels. If the hull shape of the vessel is obtuse, it will increase the water resistance of the hull to the flow. In case the propeller clearance is small, a propeller with small diameter should be used, although it might not be able to absorb all the thrust efficiently, resulting in inappropriate force that facilitates the vessel to move forward in both speed and thrust especially for trawlers and purse seiners.

Installing new propeller shaft aligned with the purpose of attaining improved propulsion efficiency and efficient utilization of fishing vessel fuel, would result in reduced total fuel consumption after vessel renovations. To provide high-efficiency thrust, the flow platform should be improved to ensure that the propeller axis is aligned with the flow pattern of the ship hull for a smooth and efficient flow of water supply to the propeller. In practice, it is difficult to install such propeller, but it is most important to have propeller clearance to the hull structure and keel (aperture size) adequate for the propeller size requirements and there must be enough space for the engine and gearbox inside the engine room.

The angle of the propeller shaft should be as small as possible compared to the keel (**Figure 2**). Thus, the design of the engine base and the transmission system should be adjusted to match the angle to support the driving force and reduce vibration. Most fishing vessel owners and skippers have misunderstood the importance of propeller clearance to avoid the enclosed distance between the propeller and the hull structure. Consequently, many fishing vessels have been set with the angle of the propeller shaft made steeper to avoid such close ranges, missing the hydrodynamics performance and the direction of the force.

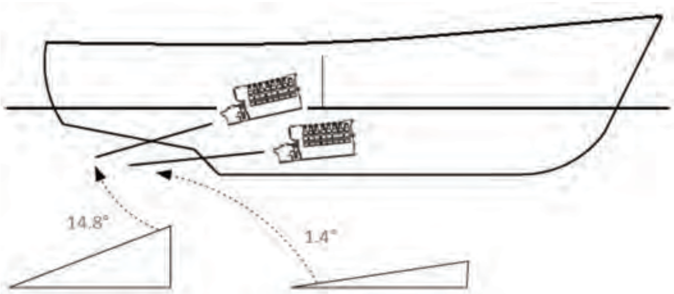


Figure 2. Adjustment in the propeller shaft alignment

To enhance the understanding and awareness of the fishing vessel owners on the aforementioned concepts, SEAFDEC/TD embarked on a six-year Japanese Trust Fund-funded Project "Optimizing Energy Use and Improving Safety at Sea in Fishing Activities" in 2013, which included the "R&D on the implementation of fishing operations with optimizing energy use." Specifically aimed at improving fishing vessel design appropriate for local fisheries in the Southeast Asian region, the R&D activity focused on the SEAFDEC/TD innovation which includes not only in upgrading the purse seine fishing vessels but also the improvement of the propulsion system and of the length of waterline, which has then pilot-tested in Pattani Province in southern Thailand, in collaboration with the Department of Fisheries of Thailand, the Fisheries Association of Pattani Province, and the owner-operator of the pilot purse seine fishing vessel (Thanasansakorn *et al*., 2019).

Renovation of the engine bed and transmission gears

The engine foundation (engine bed) should be adjusted to a lesser angle so that the propulsion engine and reduction gear are placed at the same angle of the vessel as it moves straight forward, and mounted close to the keel of the vessel (**Figure 3**). Thus, the propeller shaft angle has been changed from 14.8 ° to 1.4 °.

Figure 3. Installation of engine in the engine room

Refinement of the stern tube

After the previous propeller shaft exit had been firmly sealed *(above left)*, the new propeller shaft angle *(above right)* is installed, and a new exit is drilled at the sternpost for the stern tube installation *(below)*, as shown in **Figure 4**.

Figure 4. Refinement of the stern tube

Reinstallation of propeller blade

The angle of the propeller blade should be adjusted to higher degrees to optimize the thrust/propulsion efficiency of the fishing vessel during traveling/fishing operations.

Results of the innovation

Improvement in engine speed

Engine speed (rpm)	Vessel speed (kt)	
	Pretest	Posttest
1,850	8.0-8.5	11.0-12.0
1,500	5.0-6.0	8.0-9.0
1,200	4.0-5.0	7.0-8.0
1,000	3.0-4.0	6.5-7.0

Cost of Improvement	
Item	Amount (USD)
Materials (engine bed and mounting materials)	2,320
Labor	1,000
Docking and services	1,680
Total cost of renovation	**5,000**

The benefits gained from the innovation include:
- Increased vessel speed
- Efficient fuel consumption and reduced greenhouse gas emission by 36 %
- Reduced vibration and noise at the stern
- Smaller waves or turbulence (vortex) at the stern which means that there is less resistance

Improving the length of waterline

Fishing vessels operate at certain speed for a particular fishing gear. As the vessel speed accelerates, the wave resistance also increases, leading to efficiency loss and high fuel consumption. Reducing fuel consumption allows greater savings for the cost of fishing operations. In general, a vessel cruising at low speed consumes lesser fuel than at high speed, but such relationship is non-linear. It is therefore important to consider the optimum speed, also called the "operating speed" or "service speed," which is used to set up the speed range of vessels in operation. Such operating speed is an important factor that should be considered in improving and/or renovating the vessel design in order to increase the vessel speed capacity and reduce vessel operation costs (*e.g.* fuel cost, working days at sea, etc.).

To achieve the optimum speed, the vessel should have an appropriate L/B ratio, where L or LwL is the length of the vessel at waterline from bow to stern, when it sits on the water

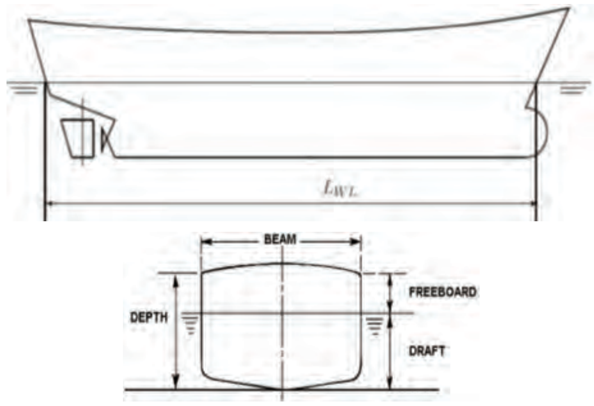


Figure 5. Vessel length at waterline *(above)* and beam or width of the vessel *(below)*

surface, and B is the beam or width of the vessel measured between the most outboard points of the vessel (**Figure 5**). The larger L/B ratio indicates slimmer hull shape and less wave-making resistance, resulting in more efficient high-speed performance of the vessel, optimized its energy used, and increased its load-carrying capacity.

In the pilot project in Pattani Province in southern Thailand, a pelagic purse seiner was improved by increasing the vessel length from 13 m to 18 m.

Renovation

Cutting of the hull structure (A); making two sections of hull structure (B); and increasing the hull structure (C) by 5 meters in length (m).

Results

	Before	After
Propulsion engine capacity	375 hp	375 hp
Breadth	4.4 m	4.4 m
L_{wl}	13 m	18 m
L/B ratio	2.95	4.09
Maximum speed (nautical mile/h)	8.601	9.944
Fuel consumption (litter/hour (l/h))	27.348 l/h	27.348 l/h
Fuel consumption (litter/nautical mile (l/nmi))	3.179 l/nmi	2.750 l/nmi
Greenhouse gas emission per hour	72.198 kg of CO_2	
Fuel consumed/equivalent to produce carbon emission/100 miles	317.963 liters equivalent to 839.422 kg of CO_2 emission	275.020 liters equivalent to 726.052 kg of CO_2 emission
Fuel saved/h or reduced carbon emission/h	4.269 l/h or equivalent to 11.270 kg of CO_2/h emission	

Cost and benefit

Item	Amount (USD)
Materials	2,350
Labor	6,300
Docking and services	3,350
Total cost of renovation	**12,000**

The benefits obtained from the renovation include:
- Bigger space is available for handling the catch onboard, more comfortable living space is created for fish workers onboard, and better ship stability
- Efficient fuel consumption
- Fresh catch arrives the markets faster and thus, commands good price

Pilot testing of the improved technology would be continued to address the issues and concerns encountered during the refinement and verification trials on optimizing energy use in fishing operations, and find the best options that could lead to further improvement of the innovations, which also include not only improving and/or renovating the operations of the physical structure of the vessels but also on the possible reduction of manpower onboard and on proper handling of catch onboard.

Specifically, this would require among others, standardizing the rate of fuel consumption per kilogram of catch, comparing the quality of fish catch and post-harvest losses per fishing trip, determining the average rate of greenhouse gases emitted by the vessels per kilogram of fish catch, and identifying the factors that lead to improved working conditions and safety at sea of fishers onboard. After refining and verifying the improved technology at the pilot sites in Thailand and other selected AMSs, this would be promoted to the rest of the Southeast Asian countries to contribute to the enhancement of sustainable fisheries development in the region.

Reduction of carbon emission from fishing operations

A privately-owned purse seiner in southern Thailand, the "NOR LARPRASERT 8 " has been commissioned by SEAFDEC/TD through a collaborative arrangement since 6 July 2018 for a pilot project on labor reduction onboard fishing vessels during the fishing operations, as well as enhancement of the working practices and living conditions onboard the vessels following proper hygiene and adopting the low-impact and fuel efficient (LIFE) fishing concepts to catch fish, and preserving the freshness of the catch at sea for the benefit of the consumers. The initial activity using this pilot purse seine fishing vessel was launched through a joint fishing operation between the local fishers and SEAFDEC staff from 8 to 12 February 2019, and continued thereafter. During the trial period, the pilot project has shown improved efficiency of the fishing gears (net plan), fishery machinery, and fish handling tools.

After more than three years of research on fuel saving/energy efficiency using this pilot vessel by adopting the appropriate technology on improving energy efficiency, SEAFDEC has contributed to the improvement of fishing practices and working conditions onboard fishing vessels, and reduction

Table 1. Summary of the data on the operation of the pilot purse seine fishing vessel (from 2019 to date)

Total fishing operation (day)	Total fishing voyage (trip)	Total fish catch (kg)	Total fuel consumption (l)	Engine operation (hr)
219	20	260,500	54,035	4,919
(l)	Ave fuel consumption per voyage or trip (l)	Ave fishing per voyage (day)	Ave catch per fishing voyage (kg)	Catch per 1.0-liter fuel consumption (kg)
10.98	2,701.75	11	13,583	4.82
Ave fuel consumption per day (l/day)	Ave selling price of catch per kg (THB)	CPUE/day (kg/day)	CO_2 emission per day ($kgCO_2$)	CO_2 emission per 1.0 kg of catch ($kgCO_2$)
246.73	30	1,189.49	651.36	0.5475

Table 2. New carbon emission recorded about the pilot purse seine fishing vessel

Ice consumption/trip reduced by	Compared to emission $KgCO_2$	New total emission/trip $KgCO_2$	New emission per 1.0 kg of catch ($KgCO_2$)
150 box = 36 t	972	6,160	0.453

Table 3. Improvements made before and after the implementation of the project using the pilot purse seine fishing vessel (2019-2021)

Aspects to be improved	Before project implementation	After project implementation
Manpower onboard (MO)	more than 30 fishers	17 fishers
Average hauling time	About 1.5 hr	30 min
Living space (LS)	72 m^2 (2 levels: 3m x 6m each) shared by 29 fishers (skipper uses different area), each fisher occupies 2.50 m^2 of workspace	72 m^2 (2 levels: 3m x 6m each) shared by 17 fishers (skipper uses different area), each fisher occupies 4.23 m^2 of workspace
Total catch (TC) recorded on logbook	260,500 kg	
Ave catch per voyage	13,583 kg	
Total gross income (at 30 THB/kg)	USD 260,500	
Fishing trip (FT): Thailand regulations indicate that fishing vessel more than 30 GT is permitted to go fishing for not over 240 days/year		219 days (11 days/trip)
GHG emission	0.5475 $KgCO_2$ to catch 1.0 kg of fish	0.4530 $KgCO_2$/kg of fish (to catch 1.0 kg)

of the manpower onboard purse seine fishing vessels. The summary of such efforts made by SEAFDEC/TD, is shown in **Table 1**.

After implementing the project, the new carbon emission record is shown in **Table 2**, while the changes and improvements comparing before and after the implementation of the project using the pilot purse seine fishing vessel, is shown in **Table 3**.

Greenhouse Gas Emission (GHG Emission) refers to the carbon emission or the release of carbon dioxide gas from burned fossil fuel into the atmosphere. Included in **Table 3** are some facts about greenhouse gas emissions from the fisheries sector considered as one of the sources of carbon emission that fuels climate change.

Fuel Consumption (FC): the rate at which an engine uses fuel, expressed in units such as voyage per liter, liters per working hour, or liters per kilogram of the catch. The pilot purse seine fishing vessel makes use of Cummins Engine brand model K-500. Since the first fishing operation until now and referring to the data record for fuel consumption, the average fuel consumption, working-hours of engine operation, and the CO_2 emitted, had been recorded in detail as shown below. For the sake of showing an example, consider 1.0 liter of diesel that weighs 835 g. Diesel consists of 86.2 % carbon or 720 grams of carbon per liter of diesel. To burn this carbon to CO_2, 1920 g of oxygen is needed. The sum is then 720 + 1920 = 2640 g of CO_2/liter of diesel. It should be noted that in the U.S.A., the electricity generated by the electric power industry results in the emission of carbon dioxide (CO_2) which is equal to about 0.99 lb of CO_2 emitted per kWh.

As shown in **Table 3**, 0.5475 $KgCO_2$ is emitted to the atmosphere while catching 1.0 kg of fish before the project implementation. After the project implementation, 0.4530 $KgCO_2$ is emitted per kilogram of fish caught.

GHG emission (before project implementation)
= 0.5475 KgCO_2 to catch 1.0 kg of fish
GHG emission (after project implementation)
= 0.4530 KgCO_2/kg of fish

Moreover, the fuel consumption of propulsion engine is 246.73 liters/day, then correspondingly the gas emitted from fuel consumption is: 246.73 x 2.64 KgCO_2 = 651.36 KgCO_2/liter.

Catch per unit Effort (CPUE): also called the catch rate, is frequently the single most useful index for long-term monitoring of a fishery. Declines in CPUE imply that the fish population cannot support the level of harvesting. Increases in CPUE could mean that a fish stock is recovering, and more fishing effort can be applied. CPUE can therefore be used as an index of stock abundance, where some relationship is assumed between that index and the stock size. The simple calculation of CPUE is the total catch divided by the total amount of effort used to harvest the catch.

$$\text{CPUE} = \frac{\text{Total catch (kg)}}{\text{Total amount of effort used to harvest the catch}}$$

$$\text{CPUE of pilot purse seine fishing vessel} = \frac{260{,}500 \text{ kg}}{219 \text{ days}}$$

CPUE = 1,189.49 kg/day
= 4.82 kg of catch/liter of fuel consumption
Or equivalent to = 1 kg of catch/0.2074 liter of fuel consumption

Reduction of labor in purse seine fishing operations

Due to the kinds of equipment being used for fishing and set up onboard many fishing vessels, *e.g.* purse seiners and trawlers, a large number of workers is required in fishing vessels, especially in the case of Thailand. For example, purse seiners require as many as 30–40 fishers onboard while trawlers require up to 22 fishers onboard. In the case of purse seiners in Thailand, heavy demand for labor comes from the enormous weight of the catch, while the nets are largely pulled aboard by hand. In view therefore of such a scenario, the Department of Fisheries (DOF) of Thailand had approached SEAFDEC/TD and with the collaboration of the Pattani Fishery Association in southern Thailand, to design a more labor-efficient purse seiner. In 2018–2019, experts from SEAFDEC/TD worked with the vessel owner on the project that aimed to design and reconfigure a 91-GT purse seiner (NOR LARPRASERT 8) based in Pattani Province, and used as the pilot fishing vessel for this project.

The design and reconfiguration of the fishing vessel included the installation of a multi-purpose crane, hydraulic system, power block, and central cooling with refrigeration system, on the purse seiner. The crane and power systems facilitate the hauling of nets that was done before by fishers, and the refrigeration system prolongs the preservation of the catch, thereby increasing its value in the market. The costs of the reconfiguration had been shared, with SEAFDEC paying for the equipment and the vessel owner paying for the installation as well as acquisition of new nets. The installation of the new equipment in 2018 took two months because of the extensive optional renovations, although SEAFDEC estimated that installation of similar equipment installation on other fishing vessels would take less than one month to complete. SEAFDEC also reported that the technology and equipment are promptly available in Thailand, and spread the information to all major stakeholders and important fishing ports of Thailand to also undertake the appropriate vessel improvement.

Cost-Benefit Analysis (before and after reconfiguration)

Before the equipment installation, the vessel required around 30 fishers for each seven-to-ten-day fishing trip, yielding a catch that was worth about USD 15,833, based on the vessel owner's price estimates and cross-checked with SEAFDEC experts. Such manning level also meant that the fishers' living space of 72 m^2 (4 levels of 3 m × 6 m space) was shared among 29 fishers (the skipper sleeps in a different area), and implied that each fisher occupied an average of 2.5 m^2 of space onboard, before the reconfiguration.

Since the installation of the new equipment in early 2019, the purse seiner has seen an approximate reduction of 37 percent in terms of labor required. The power block, crane, and hydraulic systems enable net hauling to be done more efficiently by fewer fishers. In this case, the fishers needed onboard have gone down from 27 to 17, while the average time for hauling the fishing nets is less than an hour and 30 minutes, down from more than two hours before the reconfiguration. With more adjustments, SEAFDEC forecasts that eventually, the manning will come down to 14 or 15 men, about half of the original fishing crew. The total costs of labor per year will be reduced as well, from USD 137,237 per year to USD 108,100 in the second year after reconfiguration, even with an increase of monthly wages for fishers to USD 400 per month, which is at par with past policy proposals made by Thai vessel owners and workers' organizations. The costs of workers' permit will also be reduced along with the overall cost of workforce by 45 percent (*i.e.* to approximately USD 2,633) in two years. Even accounting for the increases in base pay of the fishers, supervisors, and skippers, the savings from the total labor cost are significant at approximately 21 percent.

The central cooling and refrigeration systems have proven to reduce the quantity of low-quality fish, especially the fish caught on the first few days at sea which loses its value as the quality deteriorate from 34 percent down to around 10 percent. This means that with the current renovations, 90 percent of the catch can be sold at full market price (up from 70–80 percent of the quantity before the installation), increasing revenues by roughly 10 percent from USD 15,833 to USD 17,416 on the average per trip.

The work area onboard for fishers has also seen significant change. After the boat reconfiguration, the 72-m^2 living area is now shared by only 17 fishers (excluding the skipper), hence each fisher now has 4.23 m^2 of workspace versus the 2.48 m^2 before. This means that the fishers no longer work in such a crowded space, which has been notoriously dangerous in the fishing industry, this means safer work conditions.

Fuel costs are largely unchanged after the reconfiguration. The vessel owner however noted that any increases in fuel usage due to the installation of the crane are offset by the reduction in the number of fishers onboard. SEAFDEC has planned to change the configuration of the refrigeration system starting in late-2019 as the engineering team believes that such changes could lead to reduced energy costs. With regards to engines used in the fishing industry, certain more efficient fuel-injection engines have been in use elsewhere but these are not available in Thailand and are three times more costly than the traditional engines. As a result, most vessel owners in Thailand have reportedly shown little interest in the lower-carbon types of engines. Meanwhile, the owner of the pilot fishing vessel and SEAFDEC had estimated that the resale value of the vessel after the reconfiguration is about USD 330,000 an increase of about two-thirds of its USD 200,000–230,000 value before the changes.

Improvements in their working conditions had led to reduced turnover rate of fishers from 30 percent to effectively zero in the months after the reconfiguration. This demonstrates that the installation of basic power-hauling equipment on purse seiners can help alleviate labor shortages and improve the conditions of those working and living onboard the vessels. The total cost of the comprehensive reconfiguration carried out on the pilot fishing vessel (excluding the cost of acquiring new nets) is USD 58,330. This includes the central cooling system, refrigeration system, other installations, and the core reconfiguration: crane, power block, and hydraulic system. The investment cost for the vessel's reconfiguration is relatively high as far as the owners of even the smallest commercial fishing companies that own one or two fishing vessels are concerned. However, SEAFDEC is of the view that the investment costs could be reduced if only the core equipment are changed, *i.e.* crane, power block, and hydraulic system. The central cooling system, the refrigeration system, and the purchase of new purse seine nets are not necessary for the core reconfiguration, as vessel owners can make such additional improvements over time. Assuming that a ten percent increase in revenue per trip due to the enhanced cooling and refrigeration systems, from an average of USD

15,833 per trip to USD 17,416 per trip, at 30 trips per year, the increase in annual revenue during the second year after the reconfiguration is estimated at USD 47,500. Adding the savings from labor cost of USD 29,138 per year, the total amount could easily cover the investment cost for the reconfiguration and installations in less than one year. The summary of the cost of the vessel reconfiguration and benefits gained, is shown in **Table 4**.

Table 4. Summary of reconfiguration cost and benefits

Comprehensive Reconfiguration Cost (excluding new nets)	USD 58,333
Estimated increase in revenue per year after reconfiguration	USD 47,500
Savings from labor cost per year after reconfiguration	USD 29,000
Return on investment (estimated period)	Less than 1 year

Catch per unit of fishing effort and greenhouse gas emission of a purse seine fishing vessel are among the most important factors that determine the impacts of the increasing contribution of Southeast Asian fisheries to global seafood production. Purse seine fishing is one of the activities that significantly contribute to the region's seafood production, but requires considerations in terms of the energy use (man and machine), and in mitigating the negative impacts of fishing activities and vessel operations on the environment.

Improvement of catch preservation technology onboard fishing vessels

SEAFDEC/TD has been developing a design and also initiating the construction of onboard refrigeration system to be used for fishing vessels by adopting a hybrid technology that can make use of multi-mode operation sources, *e.g.* from the propulsion engine or diesel generator or electricity from the shoreline. In addition, the design also utilizes various types of preservation tools onboard that are more suitable for the fishing gear and target species, such as the refrigeration seawater (RSW) and airblast freezing system. The possibility of using both RSW and airblast freezing system in unison is also being explored as means of prolonging the freshness of the catch at their premium quality onboard, taking into account the optimum utilization of energy.

Refrigeration seawater

Refrigeration seawater (RSW) is a system used onboard fishing vessels to preserve the freshness of the catch. The advantage of using the RSW system is its cost-saving capacity and its ability to preserve the catch at premium quality until it is unloaded ashore or for further processing. Its cooling efficiency is improved, cooling down the catch close to freezing point much faster than using ordinary ice or limited ice, thus, ensuring the freshness and fresh quality of the catch while being transported onboard. It should be noted that the approximate electricity consumption per tonnes of ice (box) produced for the icemaker and refrigeration plant for temperate and tropical areas, is approximately 60 kWh/tonne. This does not include requirements for handling, crushing, or storage.

Airblast freezing system

The use of air flow to improve heat transfer from the product being cooled through the refrigeration system is probably the most common method used in commercial fishing vessels. However, the natural convection of the air alone would not give a good heat transfer efficiently, therefore, forced convection using fans has been introduced. To enable the product to reach the freezing point within a reasonable time, the air flow rate should be fairly high (2–6 m/s). Also, to obtain uniform cooling rates throughout the freezer, the air should flow over each fish in every fish container.

Power take-off

Power take-off (PTO) is any of several methods used for taking power from a power source, such as the main engine, and transmitting it to an application such as a water pump, hydraulic pump, and/or compressor for the refrigeration system. Usually, the refrigeration system whether in an industrial establishment or on a fishing vessel, uses an energy source which is either from the electric motor or engine, to keep the compressor of the refrigeration system going. It is designed to be capable of using more than one type of energy source which consists of the main engine and the electric motor.

Split shaft power take-offs

In a fishing vessel, the propulsion engine or diesel generator has greater capacity in delivering a relatively steady amount of torque at both high and low running speeds. Consequently, the propulsion engine or diesel generator can drive the compressor of the refrigeration system by providing enough power take-off, which is a mechanism to bring power from its operating speed that properly matches with the requirements of the refrigeration unit that utilizes the power source. Split shaft power take-offs have many advantages, making it an excellent option to capitalize on the full potential of the fishing vessels. The split shaft power take-offs are equipment like a gearbox or power take-off application that allow single or multiple pumps to be driven from a single prime mover. This multiple/split type power take-off is a combination of different propulsion technologies. In the hybrid transmission system, an electric motor performs the function in place of the engine, such as exerting force to the transmission shaft.

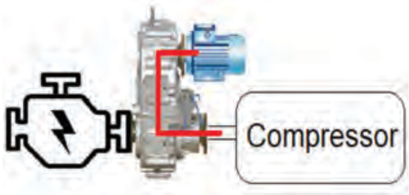
The use of split shaft power take-offs is advantageous because of their properties that include:

- Multiple outputs

- Various styles and sizes
- Standard PTO is driven by a pulley for versatility
- A shiftable compressor can drive both the electric motor and main engine
- Fuel is utilized efficiently and cost is beneficially optimized
- Waste from fish preservation onboard is reduced

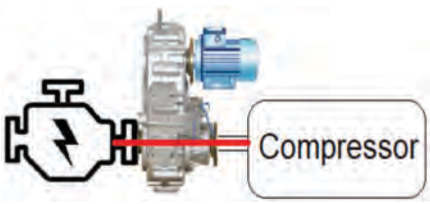
The refrigeration system could use either the electric motor or the engine, as energy source to keep its compressor going. The functions of such energy sources are summarized below:

Hybrid refrigeration system driven by electric motor



In general, the compressor of the refrigeration system is driven by an electric motor, the size of which depends on the cooling capacity or cooling efficiency of the compressor. This means that a lot of electricity is needed from the diesel generator. Since the electricity demand is defined as fuel consumption, even when a fishing vessel moored at the fishing port/jetty, it will still be able to operate the refrigeration system through the electric motor. This is because fishing vessels must continue to run either through its diesel generator ordinarily or by utilizing the shoreline power source when the main engine stops. But whenever the fishing vessel leaves the pier/port and the main engine is in use, the refrigeration system can change the mode of operation to engine mode so that the compressor would continue to function.

Hybrid refrigeration system driven by propulsion engine



The merit of the refrigeration system is driven by the propulsion engine. Whenever the fishing vessel leaves from the fishing port to the fishing ground for certain fishing period, it will take time to operate the engine. Therefore, using the engine drive mode will result in energy utilization without using the electric sourced from the diesel generator.

Way Forward

Fishing vessel owners in southern Thailand have already applied the innovation on improved fishery machinery for purse seine fishing vessels aimed at enhancing working practices and optimizing the energy utilization of their fishing vessels' operations, *e.g.* in this case where it has become necessary to make the vessel more thrust efficient, as well as improve the length of the waterline to increase the vessel speed capacity and reduce vessel operation cost. The lessons learned from the adoption of the innovations in Thailand could be shared to the other AMSs. Moreover, the R&D on the development of appropriate technologies to reduce carbon emissions to the environment at a low level in response to the issues of global crisis by climate change, and reduce labor onboard by applying appropriate hauling devices to contribute to improving the national economies and fishers' well-being onboard fishing vessels, would be enhanced and continued. The results of such activities would be shared by SEAFDEC/TD with the AMSs through the production of information and training materials/models that would be introduced through the training courses of SEAFDEC/TD on the improvement of appropriate fishing vessel technology in terms of marine engineering, and also through the SEAFDEC website. Capacity building programs through online workshops and demonstrations, as well as hands-on practical sessions could also be organized. Results of such innovations in technologies and operations could be used for the compilation of the Southeast Asian regional reference for minimizing the impacts of fishing on the environment.

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