DEVELOPMENT OF MULTI-DAY BOAT DESIGNS WITH MECHANICAL REFRIGERATION FACILITY FOR FISH STORAGE

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Summary

The spoilage of the fish in the multi day fishing boats provides a loss for the fisherman and the country's economy. It is essential to identify the suitable methods for preserving the fish at the highest quality until it is consumed by the final consumers. The goal of the project was to design a refrigeration system for the multi day boats used for fishing in Sri Lanka. The study tries to provide the design for refrigeration in range of fish holds so that the fisherman can conserve the catch with the less spoilage.

This report provides the initial requirement on the manufacturing of fish holds and the suitable design consideration to be made for the designing of the system. Further, the report provides the detail of the insulation to be used for the boats with required thermal property. The design specifications were calculated for various types of boats with different fish hold capacity. The report also explains the required guidelines to be followed by the manufacture for factory assembled installation and important installation guidelines to be followed during the installation process. A summary of the maintenance practice to be followed by the user has been provided. A financial feasibility of the design was also conducted.

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1 Introduction

Fishery sector is one of the important sectors in Sri Lanka. Based on 2016 annual report of the central bank of Sri Lanka 1.5% of the country's GDP is contributed by the inland and the marine fishing. Considering the countries consumption of fish and the overall demand in the international markets there are lots of areas to improve on this sector. Preserving of the catch in the boat is one of the important areas which requires attention. The reduced quality of the fish causes the catch to be used for dried fish and opportunity cost on the loss of export demand.

A fish starts to lose its quality once is caught in the bait. Failing to store the fish below 4^0C will cause the fish to less the quality. Sri Lanka is a tropical country where the atmospheric temperature will be around 30^0C. So the fish will start to deteriorate while it is inside the seawater. And further, an improper preserving method will lead to the reduction in the quality.

One of the major use of preserving of fish in Sri Lanka multi day boards with ice. However, quality of fish would depend on the level of insulation of the fish hold and material used for insulation. Many fishing boats in Sri Lanka use Styrofoam for insulation. Insulations properties become poor if seawater goes into the Styrofoam. Polyurethane foam would be better compare with Styrofoam. As the heat losses from the fish hold during the trip, there aren't any methods to control the temperature at the desired value.

Also, the way of storing fish in the fish hold would affect the quality of fish. Most of the local fishermen tend to pack the fish in a very dense manner so that they would be able to store more fish in the fish hold. It is always advisable to have temporary partitioned the fish hold horizontally in order to prevent the weight of the upper layer of fish would not exert on to the lower layer or bottom layer.

It is observed that in Sri Lankan fishing boat quality of fish in the bottom of the boat is poor because of the above reason. As the ice near the inner hull surface melts rapidly the quality of fish in the bottom of the boat reduces quicker than the rest.

This project provides the design and specifications for the refrigeration system to be included in the multiday boats to maintain the required temperature throughout. Depending on the boats sizes, boats have got only a fish hold, or fish hold and chilled baths or fish hold, chilled bath and bait hold. Most of the longline boats has got chilled bath and bait hold facilities in addition to the main fish hold. Therefore, design and analysis was conducted for cooling load requirement for fish storage, chilled baths and bait holds.

2 Present statistic on the fishery industry in Sri Lanka

Maritime zones

- Exclusive economic zone (EEZ) 517000km^2
- Continental shelf 30000km^2
- Historic water 21500km^2

Annual fish production (offshore) 260 020 Mt

Annual fish exports 17 460 Mt

Tuna export 9 840 Mt

* The data is for 2015 where the EU ban was on fish exports from Sri Lanka.

Fleet capacity

- Multi day boats 4218
- Inboard single day boats 719

3 Freezing of fish

Fish largely contains of 60% to 80% water. Freezing of the fish and temperature variation can be observed in figure 1. The temperature will change rapidly to just below 0^0C during the first stage of the freezing. More heat will be removed during second stage where water will be changed to ice. During the third stage, the temperature will fall rapidly but a smaller amount of heat will be removed. From figure 2 it can be observed that when the temperature reaches -5^0C about 70% of the water will be frozen and the rest of the unfrozen water will be containing higher amount of salt content.

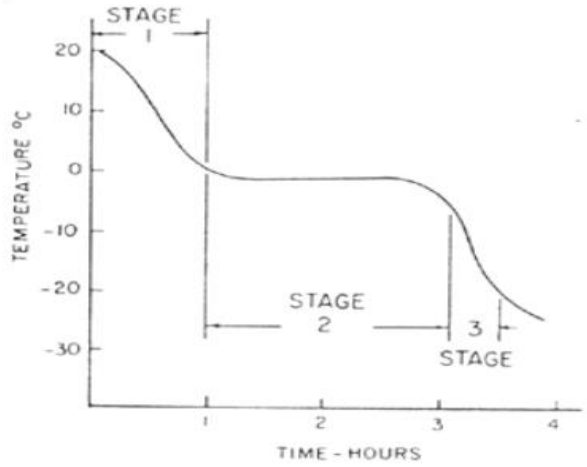


Figure 1: Temperature vs time graph for fish freeing

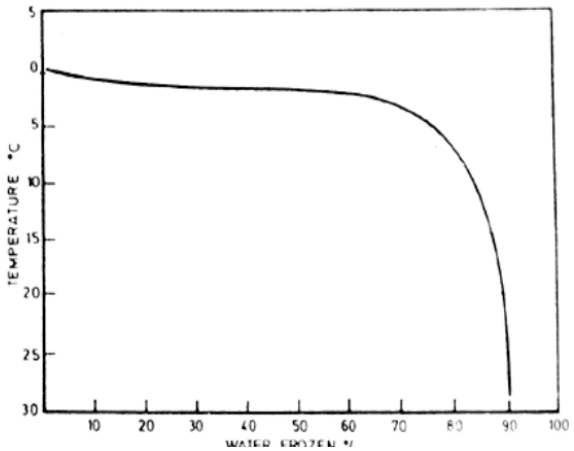


Figure 2: Percentage of water freezing in different temperature

During the process of freezing it is important to identify the time taken for the freezing. Based on the time taken for freezing process can be classified as slow freezing and quick freezing. Though there isn't a temperature to differentiate the process based on the time and temperature, it should be understand that the property of the fish can be changed with the temperature value.

Very longer freezing time will make the center portion of the fish to freeze slowly resulting in the bacterial growth and causing of the spoilage of the fish. Allowing the fish to freeze more than 12 hours will make the difference become apparent.

Though the freezing and cold storing the fish will increase the life of the fish, the quality of the fish will initially depends on the icing or chilling of the fish before the freezing operation. Therefore, it is required that the icing or the chilling operation is correctly done inside of the fishing boat.

Table 1 provides the effects of delayed chilling after the fish is hold at 10^0C for a given number of hours. As the data are collected from the Alaska region the fish is kept at a low temperature as 10^0C during the storage. Since the Sri Lanka fishing zone are situated in the tropical region the self-time can be reduced.

Table 1: Self time of fish for time taken before freezing

	Maximum shelf life[1]	Days of remaining shelf life				
Species	**Days**	**4 hr**	**8 hr**	**12 hr**	**24 hr**	**48 hr**
Halibut	18	17.3	16.6	16	14	10
Chum salmon	13	12.3	11.6	11	9	5
Sockeye salmon	12	11.3	10.6	10	8	9
Pacific cod	12	11.3	10.5	10	8	4
Silver salmon						
ocean run	10	9.3	8.6	8	6	2
mature fish	12	11.3	10.6	10	8	4
King salmon	10	9.3	8.6	8	6	2
Sablefish	10	9.3	8.6	8	6	2
Pink salmon	6	5.3	4.6	4	2	0
Pollock	5	4.3	3.6	3	1	0

3.1 Difficulty in pertaining the fish to the development of fishery industry

The major drawback of developing the industry is due to undereducated and poverty of the fishery household involved and the higher amount of risk nature of the job. These effect the community to involve on higher investment to achieve an economical advantage. A higher economical advantage can be achieved by exploring the EEZ region and increasing the catch size. To attain these advantage from exploring the deep sea, the fishing boat should equipped with necessary equipment and have the required capacity to function and the better methods to preserve the fish.

With the current fish preserving methods such as icing it is harder to preserve the whole catch to the acceptable quality. The failure of the icing are due to the following reason;

a) Heat loss from the fish hold are not been compensated therefore cannot store the fish for longer period

b) Not properly following the required procedure to store the catch at the optimum temperature

c) Heavy load on the fish when they are stored

3.2 Fish preservation at the sea

Different type of fish preserving methods are employed in the multi day boats. These are limited to the boat size and the type of fish catch. On the other hand the objective of the fish preservation are also depended on the methods employed for preservation.

3.3 Methods that are used for fish preservation

a) Chilled sea water cooling (CSW)

b) Refrigerated sea water cooling (RSW)

c) Icing

d) Freezing

   a) Blast freezing

   b) Horizontal plate freezer

   c) Vertical plate freezer

3.3.1 Chilled sea water cooling

In CSW the catch will be stored inside a tank containing sea water and ice. The advantage of this method is that there won't be any weight acting on the fish that will harm quality.

Major drawback of these method is that the increased salt contain in the stored fish. As the catch are mostly sold to the final consumers it is required that the salinity of the fish should be lower or else it will provide an undesirable taste. Few types of fish such as salmon are used to store in the CSW system. Further if the fish is processed for industrial purpose then CSW can be considered.

The salt content of the fish mainly depends on the salt concentration of the sea water and the number of days it is stored. Mostly it is not desirable to store more than 7 days in salt water or the salt content will increase.

CSW is currently employed in some of the multi day boats in Sri Lanka. The catch is stored in fish box with sea water and ice. These crates are stored inside the fish hold. Since the variety of fish are been

caught by the fisher man during a trip it will not advisable to store the fish such as tuna inside a CSW tank. Therefore, storing in crates will provide the fishermen to catch many types of fish.

3.3.2 Refrigerated sea water

In RSW the sea water is cooled by the refrigerated plant. RSW system is an efficient way of preserving the fish. Similar to CSW system salinity of the preserved fish will be a major problem.

Compared to the CSW system the salinity will be higher in RSW system. But it is required for the crew to check whether to add ice continuously into the system to maintain the optimum temperature. If ice is not add regularly to temperature of the CSW can increase more than 4^0C. Therefore, RSW systems become reliable compared to the CSW system.

Salt update

Table 2:Salt update in fish preserved in RSW and CSW

Days	RSW	CSW
5	0.3	0.1
9	0.5	0.1
15	1	0.1

3.3.3 Icing

This is the process commonly used by the multi day fishermen. Since around 70% of the Sri Lanka catch is Tuna, chilling in the sea is the best method available for the stowage of the fish. There are two stage of the chilling process, which are precooling the catch and storing the catch with ice.

During the precooling stage, the fish is placed inside tank with chilled sea water and allow the fish's center portion to reach temperature below 0^0C. Then the chilled fish are moved to the fish holds and they are stored with alternative layers of fish and ice. Since the fish are stored in a low temperature it is effective in dealing growth of psychrophilic bacteria, which are primarily responsible for the spoilage of non-fatty fish. But the heat loss from the fish hold causes the ice to melt and allowing the temperature to rise inside the fish hold. On the other hand, the fish will start to loss it's quality due to the pressure exerted on the bottom of the fish. On overall the loss will be due to above mentioned two causes.

Since the spoilage of the fish is higher due to any compensation for the heat loss the catch cannot be stored for longer period. It prevents the fisherman for staying for longer period in the sea even maximum capacity of the catch has not been achieved.

3.4 Fish freezing methods

3.4.1 Vertical/horizontal freezing plates

The catch is stored inside the shelves with refrigerated pipe coils where the refrigerant are circulated to provide the refrigeration effect. The drawback of this method is that the certain size of fish can be used in this method. Another freezing method has to be included in the boats to accommodate for larger fish size. This method can become uneconomical for the boat sizes used by the Sri Lankan fishermen.

3.4.2 Blast freezing

Blast freezer are used for quick freezing of fish where cold air is circulated inside a chamber. Requirement of higher investment and higher cost of operation makes the method as an undesirable method. The objective of using blast freezer to preserve the fish for longer period such six months, which exceeds the scope of the fish preservation of offshore boats in Sri Lanka.

4 Design guidelines

4.1 Boat size and Fish hold capacity

The available size for the fish holds depends on the size of the boats and the engine room size. Based on the initial collected data following sizes for the boats and the fish hold sizes were identified. Based on the initial data the boats were classified into two categories.

a) Class 1: Multi day boats with fish holds

b) Class 2: Multi day boats with fish hold, bait holds and slurry tank

Further the Class 2 can be further classified based on the size of the boats and the suitable design and condition for the boats.

Class 2 boats;

a) 10 m3

b) 15 m3

c) 20 m3

d) 25 m3

e) 30 m3

Based on the above classification following systems have been selected for the designing condition,

- Class 1 type boats the it is required for the customers to select for RSW system or refrigerated fish hold based on the user requirement
- Class 2 type boats fish hold, slurry tank and the bait hold has to be refrigerated separately

4.1.1 Fish hold volume and boat dimension

Based on the statistical calculated by the FAO on fishing boats a relationship was developed between the fishing boats and the boat dimension and the fish hold volume to an accuracy of 10%. The fish hold volume is measured based on the cubic number(CUNO) where is calculated as:

CUNO: LOA x B x Dm

Where: LOA: Length overall

B: Beam width amidships at deck level

Dm: Distance from deck to keel

And the fish hold volume corresponds to the CUNO x 0.14.

4.1.2 Insulation and Subdivision of Slurry Tanks or Chilled bath

When carrying seawater in tanks, the free surface of the liquid would affect the stability of the vessel and hence always advisable to longitudinally subdivide the chilled bath so that single tank would not extend throughout across of the breadth. No of subdivision should be determined based on the size of the tank.

Insulation and watertight integrity of the such tanks are very important. There should not be any provisions for leaking of seawater to the insulation and lamination chilled bath after the insulation should be done with proper care and attention should be paid when fixing discharge and charging pipelines so that there are no leaks into the insulation.

4.2 Refrigerant type

R134a was considered as the refrigerant for the design based on the following condition,

a) It is non-flammable and low toxic

b) With the ban R12 and R22, R134a has the similar physical and thermodynamic property as the former refrigerant

c) Environmental friendly refrigerant

For the lubricant Polyalkylene glycol (PAG) type has to be used for the compressor. It is also recommended to go through the compressor brand to check the suitable lubricant (PAG46, PAG100) before selecting the lubricant type.

4.3 Refrigeration system type

There are two types of refrigeration cycle that can be adopted into the system. Those are vapour compression cycle and the absorption cycle.

4.3.1 Absorption cycle

The absorption cycle will have an arrangement shown by figure 3 where an input heat will be provided at the absorber and a pump will be used to recirculate the refrigerant. Though the engine waste heat can

be considered as option of input energy it can be insufficient and additional heat has to be provided when the boat is at rest. Comparing to the vapour compression cycle absorption cycle will have a lower efficiency value. Therefore, absorption cycle isn't considered for the design.

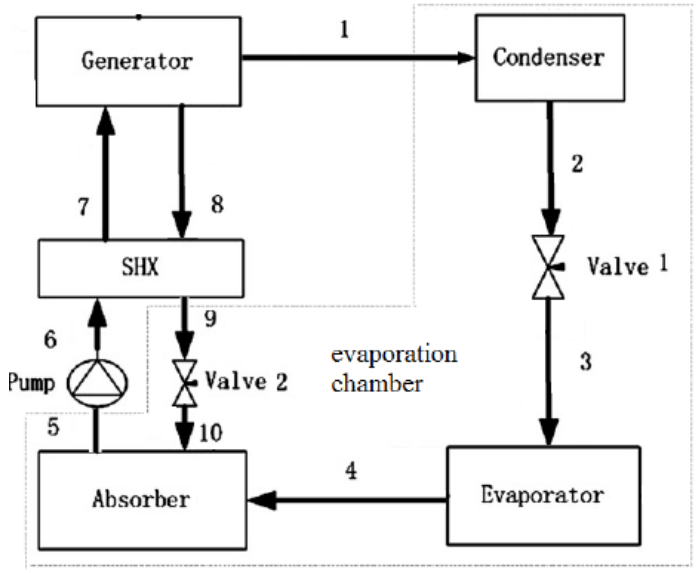


Figure 3: Absorption cycle

4.3.2 Vapour compression cycle

The system operates based on the reverse Carnot cycle. A basic diagram of the cycle has been shown in figure 4. The basic cycle will have following component,

- Compressor : Work input device for the cycle where the electrical input power has to be provided
- Evaporator : Operates at a lower temperature and removes heat from the conditioned space. The type of the evaporator can be selected based on the type of operation. For system with sea water cooling the shell tube heat exchanger can be used as the evaporator. If the cooling has to be done for open space fin and tube type with fan or a plate type evaporator can be selected for the operation.

- Condenser : Rejects heat into the atmosphere from the cycle. Similar to the evaporator based on the cooling medium the type of condensers can be selected. But for the boats there is plenty of sea water is available for cooling and the water cooled condenser will have a higher efficiency than the air cooled condenser. Therefore, sea water cooled condenser was selected for the cooling operation. The sea water condenser will be built with materials that can prevent corrosion by seawater and should withstand the scaling problem.

- Expansion valve : Reduce the pressure of the refrigerant from the high pressure to low pressure. There are different types of expansion valve available in the market. Coil type, thermostatic expansion and automatic expansion valve.

Further the cycle will contain auxiliary devices to protect the equipment and to provide the required efficiency.

Auxiliary devices

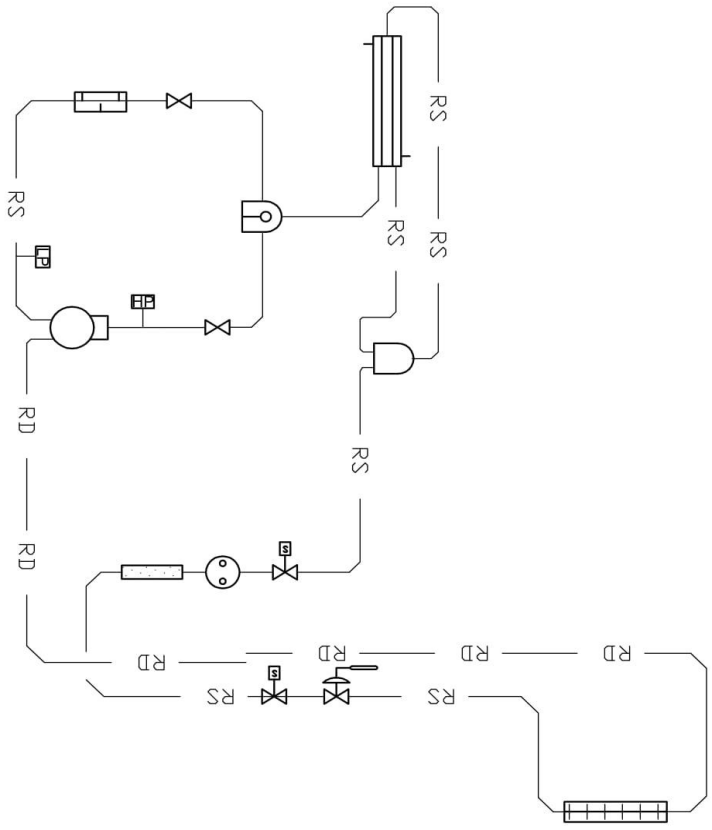
- Receiver : This ensure that only liquid type refrigerant will reach the expansion valve.

- Strainer : Strainer will allow the removal of any containment or the lubricant before it reaches the expansion valve.

- Pressure regulating valve : Refrigeration system with multiple evaporator coil temperature and with single compressor require each evaporator pressure is maintained at the designed pressure value for the best mixing of the refrigerant.

- Oil separator : Lubricant has to be inserted into with refrigerant when it is reaching the compressor. This will protect the compressor component from damaging during the operation. But the lubricant has to be removed from the refrigerant before it reaches the condenser.

- Defrost heater : Since the temperature of the evaporator is below -3^0C frosting on the evaporator coil can reduce the capacity of the evaporator. Therefore an defrosting heater has to be operated few minutes to defrost when frosting temperature is reached at the sensor.



SYMBOL	DESCRIPTION
	HIGH PRESSURE SWITCH
	LOW PRESSURE SWITCH
	SOLENOID VALVE
	GATE VALVE
	MUFFLER
	DRIER
	SIGHT GLASS
	THERMAL EXPANSION VALVE
	OIL SEPERATOR
	RECEIVER
	EVAPORATOR
	CONDENSER
	COMPRESSOR
— RS —	REFRIGERATED SUCTION LINE
— RD —	REFRIGERATED DISCHARGE LINE

Figure 4: Vapour compression cycle

5 Insulation of fish hold

In refrigeration system, it is required to have proper insulation system to reduce the heat loss from the conditioned space and to ensure a lower refrigerant capacity is used for the space. Considering the insulation for the fish hold following requirements are considered

- Thermal conductivity : The material to be selected for the insulation should have a smaller thermal conductivity value. For such material heat loss to the environment can be reduced with the smaller thickness material. Generally, fiber glass, Polyurathene and Styrofoam are considered for insulation material.

- Durability : Since the insulation can be exposed to the sea water the insulation should not loss its quality during the useful life of the boat. If the material can not be retained the property during the lifetime, the heat loss will be higher and the a lager replacement cost will associate with the boats.

- Cost : The material should be cheaper when considering the economic feasibility.

Characteristics of the fish container materials used for the fish hold has been provided in table 3,

Table 3: Fish hold container material property

Type of material	Density	Thermal conductivity
Plywood	530	0.14
Aluminum alloy	2740	221
Fiberglass reinforced plastic	64-144	0.036
HDPE	960	0.5

Type of insulation material used for the insulation purpose,

Table 4: Insulating material and properties

Insulating material	Thermal conductivity per inch	Advantage	Disadvantage
Polyurethane board	0.908	Good thermal conductivity, can be used with fiberglass resin	Expensive
Polyurethane spray	0.8	Good thermal conductivity, can be used with fiberglass resin	Expensive
Polyurethane poured	0.8	Good thermal conductivity, can be used with fiberglass resin, ease to apply	Expensive, Required calculation on volume calculation
Styrofoam	1.13	Readily available, low cost	Cannot be used with fiber glass unless protected
Fiberglas wool batt	1.79	Low cost	Absorb water loss insulating value when wet
Rock wool batts	1.53	Low cost	Absorb water loss insulating value when wet
Saw dust	2.55	Low cost	Absorb moisture and loss R value
Air space			Has to be completely sealed for infiltration

Table 5: Polyurethane insulation property

Type of polyurethane	Density
Spray – low (open cell type)	8
Spray – Medium (close cell type)	32
Spray – High (close cell type)	48

The insulation characteristic of the material losses when the material is contacted with water or moisture. As for certain fish hold container tends to allow the moisture through them. Therefore, it is required that the insulation should be vapour proof. Fish hold should have a moisture barrier to prevent the moisture entering the insulation from outside and a water barrier to prevent the melted ice not entering the insulation. The vapour barrier can be achieved from the prefabricated insulation panel, reinforced plastic materials, polythene sheets or plastic film films of minimum thickness of 0.2mm. The insulation material should also have the non-flammable and non-explosive property.

It is also essential that the boat manufacture should take higher precaution to avoid the bilge water mixing with the insulation. The drain system should be designed and constructed properly so that the water will not allowed to go inside the insulation layer. It also important for the manufacture to ensure that the all connecting edges of the fiberglass boards are water sealed.

The Polyurethane insulation can be installed in fishing boats in three methods:

- Prefabricated blocks
- Spray foam
- Pour foam

Prefabricated blocks will have a higher density and better insulating property. But during the insulation process the air cavity can be formed between the insulation and these air cavity have a poor insulation property compared to the Polyurethane.

The Spray foam is where the Foam and A and Foam B are sprayed directly to the walls of the fishing boats walls through a special equipment. With respect to the concentration of the two foam the density of the spray can be controlled which provides a better thermal property for the insulation.

In pour foam is applying the foam is similar to the spray foam insulation but here instead of spraying the liquid directly to the wall the liquid is poured inside the two-fiberglass layer through small holes. When

the liquid starts to expands it occupy all the inner volume. It is required to control the quantity of the foam. I smaller quantity is used the volume will not be fully covered and the boat manufacture cannot ensure it. And also using the larger quantity will develop larger pressure during expansion inside of the cavity and deform the outer layer of the fiberglass.

Design has been done based on the suggested insulation for the boats. Since this insulation will have a heat resistance property and the required size and cost of the refrigeration system will be lower.

Table 6: Suggested insulation arrangement

Insulation materials	Thickness (mm)	Conductive heat transfer coefficient (W/mK)
Fiberglass (outer)	5	0.036
Polyurethane	150	0.042
Fiberglass (inner)	3	0.036

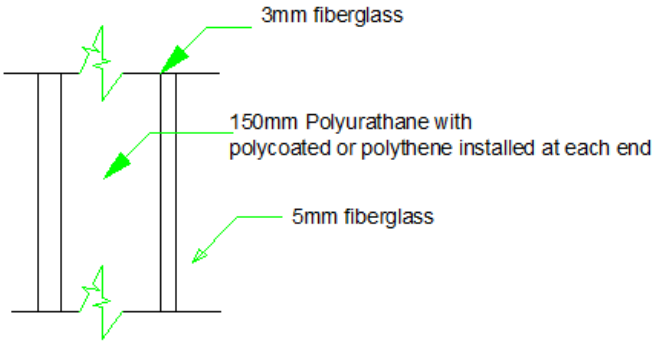


Figure 5: Insulation arrangement

Since the infiltration load is one of the mode of heat loss from the fish hold the heat loss can be prevented be partitioning the fish hold into smaller compartments. These fish hold compartment can be fully closed once they are filled by the catch. This will prevent the temperature increase in fish due to the infiltration.

When refrigeration system will be installed into the system then cooling grid concept will be adopted. The design will require an air gap to be allowed between the catch and the fish hold. From this the

refrigerated air can be allowed move around the fish hold and the heat from the wall will be removed from the conditioned air and not from the catch stored inside the fish hold.

Refer section 11.2 For the budget of implementing the Polyurethane insulation for fish hold.

5.1 Heat loss on the fish hold

Heat loss in the fish hold causes the quality of the fish to reduce and to reduce the number days the fish can be stored. In a fish hold the heat loss can happen due to three reasons, which are

a) Heat loss by conduction - Heat loss through the wall of the fish hold due to the temperature difference between the fish hold and outside air.

b) Heat loss by infiltration – The heat loss from the fish hold because of the air leaks and the air change occurring when the fish hold is opened.

c) Heat generated by the fish decomposition – The decomposition of the fish will start when the fish has died. Not properly freezing will allow the bacterial growth in fish and the temperature to increase.

6 Calculation for the design

The following chapter illustrates the theoretical models used for the calculation of the refrigeration system and the heat transfer devices. Some area of the calculation involve few uncertain variables. Uncertainty on these variables are due to the actual model can vary from the theoretical model available for design. Whenever uncertainties are encountered during the design factor has been has been added to the design parameters based on the other literature.

6.1 Design condition

Outdoor temperature : 34^0C

RSW tank temperature : $(-1)^0$C - 0^0C

The freezing temperature of the seawater depends on the salt content. The freezing temperature of the sea water in the near Sri Lanka coastal region is -1.34^{0}C. Therefore -1^{0}C is considered for the slurry tank temperature.

Fish hold temperature (If stored with ice without chilling) : 2^0C - 0.5^0C

Fish hold temperature (If stored without ice) : -1^{0}C

Improper chilling and the heat generated during the bacterial growth has to be removed by the melted ice inside the fish hold. The heat transfer rate between the fish and the ice will be higher when the fish is contacting with the water than the ice. So, it is recommended to maintain the temperature of the fish hold at 2^0C. Ice can melt and compensate for the heat loss.

Bait hold temperature : -15^{0}C

Refrigerant : R134a

Evaporator coil temperatures : 5^0C lower than the required conditioned space temperature

Condenser coil temperature : 46^0C

- It is required for the manufacture to ensure that the given conditions are met during the refrigerant refilling process to achieve the required temperature.

6.2 Cooling load

heat transfer through the wall is calculated using the following equation,

$$Q = UA(\Delta T)$$

where,

Q = heat transferred through the wall

U = Overall heat transfer coefficient

A = Cross sectional area

ΔT = Temperature difference between the fish hold and outside

6.3 The overall heat transfer coefficient

The overall heat transfer coefficient is measured by the steps provided in the following steps,

Heat transfer coefficient is measured using equation (2)

$$R= K1/d1+ K2/d2 + \ldots\ldots\ldots\ldots..$$

R = R - value

K = Heat transfer coefficient

d = thickness of the wall material

The infiltration load of the fish hold will be provided by the equation (3).

$$Q = kV\rho C_p \Delta T$$

where, k = number of volume change

V = volume of the chamber

C_p = Specific heat capacity of airConvective heat transfer coefficient

Measure the overall heat transfer coefficient the convective heat transfer coefficient has to be measured. The convective heat transfer depends on the geometry of the fluid flow and the fluid. The Kandikar

correlation (1990) was used for the measurement of the two – phase forced convection heat transfer coefficient.

$$H_{tp} = \max\{h_{NBD} , h_{CBD} \}$$

$$h_{NBD} = h_l [0.06683 CO^{-0.2} + 1058 BO^{0.7} F_{fl}]$$

$$h_{CBD} = h_l [1.1360 CO^{-0.9} + 667.2 BO^{0.7} F_{fl}]$$

$$CO = \left[\frac{1-x}{x}\right]^{0.8} \left[\frac{\rho_g}{\rho_l}\right]^{0.5}$$

$$BO = \frac{q}{Gh_{fg}}$$

where,

h_l = Single phase heat transfer coefficient

CO = Convective number

BO = Boiling number

F_{fl} = Fluid dependent parameter (for R134a = 1.63Freezing time of the fish

The time taken for the fish center portion to reach the freezing temperature is measured by the modified Planck equation. The freezing time is required to ensure that the fish reaches the freezing temperature in 12hrs.

Modified Planck equation;

$$t_f = \frac{\Delta H}{T_f - T_\infty}[\frac{Pa}{hc} - \frac{Pa^2}{K_i}]$$

$$\Delta H = (1+0.008T_i)[C_{pu}(T_i - T_f) + L_v + (T_f - T)$$

where;

hc = convective heat transfer coefficient

Tf = initial freezing point

K_i = thermal conductive of frozen food

T_∞ = ambient temperature

Lv = Latent heat of freezing

7 Cooling load

A safety factor of 30% was considered for the measurement of the boats, because

- The shape of the fish hold was rectangular, but on real boats the due the curved body the surface area of the boats can change
- Increase in the engine room temperature

In addition to the given safety factor 2% conditioned space area was considered without any insulation. The addition was required since air cavity formed between the edge of the adjacent insulation sheet will have an overall heat transfer coefficient of approximately 20 times.

The bait hold and the slurry tank volume are mostly similar for all category of boats. Based on the condition the cooling loads was calculated for the bait hold volume of $5m^3$ and a slurry tank volume of 6m3. Based on the selected volume the cooling load for bait hold and slurry tank as follows,

a) Bait hold - 671 W

b) Slurry tank – 2567 W

The cooling load for the fish holds with $5m^3$ bait hold and $6m^3$ Slurry tank are as follows,

Table 7: Cooling loads for different fish hold volume

Fish hold volume (m^3)	Cooling load (W)
10	1101
15	1427
20	1787
25	2106
30	2508

$10m^3$ fish hold only - 1837W

$12m^3$ RSW – 3317W

7.1 Ice requirement

For fishing boats without any refrigerated system or a slurry tank to precool; the catch should be preserved with ice to fish weight ratio of 2:1.

The calculation for Ice requirement with refrigeration system has been done based on the following assumption,

- 20 days trip with 15 days self-life of fish
- Fish hold with three partitions
- At the end of the trip catch size will be 100% of the fish hold

For the refrigerated fishing boats without slurry tank the fish will be cooled by the by the ice and refrigerated system will allow the temperature to be maintain at 2^0C during the whole trip. Therefore, ice to fish weight minimum ratio of 1.2:1 should be used for the storage. During the initial trip the fisher man can consider on taking ice at a ratio of 1.5:1 ratio considering the climatic change, the wastage of ice during process and a smaller compensation for the ice melting when the refrigeration system is turned off.

For a multi-day boat with refrigerated fish hold, bait hold and slurry tank a smaller quantity of ice will be required for the preserving of the fish. The smaller quantity is required for the following reasons,

- A fish should be cooled up to the center line of the fish and failing in the slurry tank should be achieved at the fish hold. And water is better cooling agent than the air.
- The water melting from the ice helps to washout the bacteria from the fish surface.

8 Design concept

Design, manufacture and installation of each of the components has to follow and conform to the manufacture standards. For refrigerant piping, including the pipe sizing and the insulation thickness should be provided in the detail drawings. The boat manufacture can do modification on the size of the fish hold, bait hold and slurry tank arrangement and the volume of each of the component. Any modification to the recommended insulation and the volume of each compartment should be consulted before implementing the refrigeration system.

The equipment selection condition is provided at the appendix.

8.1 Refrigeration section

The refrigeration section shall include the refrigeration circuit, wiring, and safety controls, and will operate down to -20^{0}C of indoor temperature without short cycling while delivering not less than 100% of the rated cooling capacity.

Table 8: Equipment's on the refrigeration side

Component	Image	Destination	Brand
Compressor			Bitzer/Danfoss
Sea water condenser			Bitzer
Evaporator		Fish hold/ Bait hold	
		Slurry tank	
Service valve			Danfoss

Solenoid valve		Fish hold/ slurry tank / bait hold	Danfoss
Thermostatic expansion valve		Fish hold/ slurry tank / bait hold	Danfoss
Pressure cutout			Danfoss
Pressure regulating valve			Danfoss
Check valve			Danfoss
Drier			
Thermostats			
Sight glass			

Receiver			

a. Compressor : Semi hermetic type compressor and the capacity reduction on the compressor shall be obtained by the speed control of the compressor. A timer should be provided to prevent short cycling when shut down by safety valve. The compressor should be provided with the oil separator and BSE32 Polyolestor oil should be used. If boat manufacture selects a different compressor model he should select the appropriate lubricant.

b. Coils : Should be constructed of seamless stainless steel tubing and with steel fins bonded to tubes where it is required. The coils should be coated with corrosion resistance. Circular type fins should be selected for the manufacturing of evaporator coils for fish hold and bait hold.

c. Evaporators : The bait hold evaporator should be defrosted with the hot air from the engine room. Immiscible plate coil evaporator should be used for the slurry tank cooling. The plate coil evaporator should be made of stainless steel.

d. Expansion valve : Thermostatic expansion valve shall be used for the expansion valve. The valve should be available with internal or external equalizer and with capillary tube and bulb. Bulb charge should be determined by the manufacture such that the liquid will always inside of the capillary tube.

e. Condenser : Shell and tube type heat exchanger with sea water resistance should be selected for the condenser.

8.1.1 Controls

Controls should include, thermostat and pressure switches to regulate the space air temperature. The thermostat will be used to identify the temperature and the solenoid valve will be attached at each evaporator coils to turn on and off. Two pressure switches (high and low) should be attached at the compressor inlet and outlet to protect the compressor from failure.

8.1.2 Refrigerant piping system

Refrigerant piping, valves, fittings and accessories shall be compatible with the refrigerant used and should be capable of withstanding the pressure and the temperature. Piping layout will identify all valves and fittings.

8.1.3 Valves

Valves shall be designed, manufactured and tested specifically for refrigerant service. Valves 25mm and smaller should be brazed and valves larger than 25mm should have flanged end connection. Threaded end connection can only be used in pilot tubes or gauge lines where maintenance disassembly is required and flanged connection cannot be used. Control valve inlet should be connected with a strainer where recommended or required by the manufacture. Charge and receiver valve shall be of manufacture configuration.

Solenoid valve : Each evaporator should be operated by the solenoid valve which are controlled by the thermostat. Normally opened type valve should be selected.

Pressure regulating valve (PRV) : PRV should be connected at the suction line of the evaporators in fish hold and the slurry tank.

Check valve : Check valve will be connected at the suction line of the bait hold to prevent the high pressure gas returning into the bait hold evaporators. The valve should be swing or lift type as required to provide shutoff at the differential pressure.

Shut off valve : Valve shall be globe or ball type valve especially packed for refrigerant service.

8.1.4 Piping accessories

Filter driers : Drier should have a full flow replaceable core type. Core should be suitable that it will remove water, acid and foreign material from the refrigerant.

Sight glass : Assembly should be pressure and temperature rated and constructed of materials suitable for the service.

8.1.5 Fittings

The appropriate fitting should be selected for the refrigerant piping system based on the actual shape of the boat. The fittings should to soldered together ensuring that there aren’t any fumes inside of the joints.

8.1.6 Insulation

Suction and discharge refrigerant pipe lines which are exposed to the other than the conditioned space should be insulated with 25mm thickness flexible elastomeric material.

8.1.7 Pipe sleeves

Pipe sleeves should be provided where the refrigerant pipe passes through the walls. The sleeves should have sufficient length and the space between the refrigerant pipe and the sleeves should be insulated with polyurethane insulation.

8.1.8 Sea water section

Table 9: Equipment on sea water side

Sea water side		**Location**
Sea water pump		Engine room
Service valve		Engine room
y-strainer		Engine room
check valve		Engine room

Condenser will be cooled by the sea water.

Pump : A pump with the stainless steel impeller should be installed with the pump.

Piping : Sea water piping should be done with stainless steel pipes of schedule 40.

8.2 Installation

8.2.1 Equipment installation

Install equipment and components in a manner to ensure proper and sequential operation of equipment and equipment control. The installation of the equipment should follow the manufactures instruction or recommended by the manufacture representative. Provide proper foundation for mounting of equipment, accessories, piping and controls. Foundation for equipment shall conform to the manufacture recommendation. The refrigerant driers, sight glass and strainers in refrigerant piping should be installed in accordance to the manufacture recommendation. The driers have to be installed in the liquid line with service valves and a bypass line. Install drier at the downstream of the drier.

8.2.2 Pipe installation

Install pipe with sufficient flexibility to provide for expansion and contraction due to temperature fluctuation. Pipe joints shall not be located where pipe passes through wall structures. They should be located where they can be easily inspected. Provide sleeves for line passing through the wall.

8.2.3 Solenoid valve installation

Install solenoid valve in horizontal lines with stem vertical and with flow in direction indicated on valve. If not incorporated as the internal part of the valve, provide a strainer upstream of the solenoidal valve. Provide service valve upstream of the solenoidal valve, upstream of the strainer, and downstream of the solenoidal valve. Remove the internal part of the solenoidal valve when brazing.

8.3 RSW water circulation system

The supply pipe of the RSW system should be connected between the primary tank and the secondary tanks. At the end of the pipe system sprinkler heads should be connected and place inside of the secondary tanks. The return water pipe line between secondary tank and primary tank will be driven by the pressure difference of the water height. Therefore, it is required of the contractor to place the pipe line with minimum resistance to flow.

8.4 Testing

Upon completion of installation of refrigeration system, test factory and field installed refrigerant piping should be tested for leak. During the nitrogen boosting into the system check for pressure drop in the system. If leaks are detected at time of installation or during operation remove entire refrigerant charge from the system, correct leaks, and retest system.

8.4.1 Charging and start-up test

After the leak test if the system is found to be without leaks evacuate the system with reliable gage and vacuum pump. After charging of the system check all the components are operating properly. Adjusting the control instrument automatically or manually check all equipment's are operating properly and in the correct sequence.

9 Maintenance

A better maintenance practice should be followed by the plant owner after each trip and a annual maintenance by a technical person or a maintenance engineer.

Compressor

- All the electrical and valve connection should be checked for proper connection.
- All the pressure control should be checked and make the liquid line solenoid valve closes and compressor stops and shuts off the cycle.
- Check for the oil level in the system and it should be between one third or two third of the sight glass.
- Check for the defrost timer. It should delay the start between 3minutes and 6 minutes.
- Check for the refrigerant level. The liquid line sight glass should be clear and full 0f liquid.
- Check the insulation and ensure that there aren't any damages in it.

Evaporator

- Check the electrical connection of the defrosting system and ensure that the defrosting system is working properly.
- Check the strainers and clean or replace the strainers.
- Clean the surface of the evaporator coils.

Condenser

- Check for the scaling of the condenser pipes.
- Check the operation of the condenser pump and the electrical connection to the pump
- Check the y-strainer and clean and replace the strainer.

Insulation

- Check for any accumulated water at the bottom of the insulation after each trip
- Check for any damage to the inside of the fish hold

10 Financial analysis

10.1 Refrigerated system

The profit gained from the prevention of the spoilage of the fish should cover the initial investment cost and the operation cost of the fish. It is also considered that the spoilage of the fish will be reduced to 15% from 40%. Since tuna is the highest ratio of catch in Sri Lanka Tuna price was considered as the base price. From the considered condition, the payback period for each fish hold will as follows;

With tax

Table 10: Payback period of refrigerant plant – with tax

Fish hold volume (m^3)	Catch size (kg)	Investment cost with tax (Rs)	Operation cost per trip (Rs)**	Payback period (years)
10	3000	2,546,000	33,872	4.3
15	4500	2,575,000	114,912	2.94
20	6000	2,792,000	114,912	2.53
25	7500	2,817,000	155,952	2.2
30	7500	2,843,000	155,952	2.21
$10m^3$ ***	3000	1,251,000	32,832	1.49
RSW	6000	1,487,000	41,040	0.72

Without tax

Table 11: Payback period of refrigeration system without tax

Fish hold volume (m^3)	Catch size (kg)	Investment cost without tax (Rs)	Operation cost per trip (Rs)**	Payback period (years)
10	3000	2,211,000	33,872	3.8
15	4500	2,236,000	114,912	2.67
20	6000	2,425,000	114,912	2.32
25	7500	2,446,000	155,952	2.03
30	7500	2,469,000	155,952	2.04
$10m^3$ ***	3000	1,087,000	32,832	1.28
RSW	6000	1,291,000	41,040	0.6

* The above calculation was done for the boats where the fish are stored in the boats for 15 days and an average trip of 10 per year. The above assumptions were made based on the maximum allowable days in the fish hold without any spoilage.

** The operation cost is the additional cost that will incur in operating the refrigeration system per fishing trip

*** Fish stored in fish hold with ice without chilling in slurry tank

10.2 Insulation cost analysis

Polyurethane was considered as the insulating material due to its better heat resistance and durability compared to the Styrofoam insulation used currently. The polyurethane insulation can be installed either as prefabricated sheets or spraying the mixed polyurethane foam A and foam B. The cost of the two methods are as follows,

- Polyurethane sheet (8' x 4'x3$\frac{1}{4}$") = Rs 10,950.00
- Polyurethane foam A and B per kg = Rs 1,550.00

Based on the above two method the cost for insulating the fish hold for each of the fishing boat as follows,

Table 12: Insulation cost estimation

Boat	Cost		
	Polyurethane sheet	Polyurethane spraying (medium)	Polyurethane spraying (low)
10m^3 fish hold, 5m^3 bait hold & 6m^3 slurry tank	LKR 395,290.98	LKR 467,976.00	LKR 116,994.00
15m^3 fish hold, 5m^3 bait hold & 6m^3 slurry tank	LKR 455,872.93	LKR 539,697.60	LKR 134,924.40
20m^3 fish hold, 5m^3 bait hold & 6m^3 slurry tank	LKR 516,517.73	LKR 611,493.60	LKR 152,873.40
25m^3 fish hold, 5m^3 bait hold & 6m^3 slurry tank	LKR 569,558.37	LKR 674,287.20	LKR 168,571.80
30m^3 fish hold, 5m^3 bait hold & 6m^3 slurry tank	LKR 639,755.51	LKR 757,392.00	LKR 189,348.00

The spray type insulation can be applied at low density or as medium density. Compared to the low-density polyurethane the medium density polyurethane will have a higher heat resistance and a lower water vapor permeability.

The foreign exchange rate during the financial analysis,

1 EUR = 172 LKR

1 INR = 2.37LKR

1 USD = 152 LKR

APPENDIX A: Equipment selection condition

10m^3 fish hold with slurry tank and bait hold

Table 13: Equipment schedule for 10m^3 fish hold, 5m^3 bait hold and 6m^3 slurry tank

Boat construction condition		
Fish hold	10	m3
Bait hold	5	m3
Slurry tank	6	m3
Cooling load		
Fish hold	1051	W
Bait hold	655	W
Slurry tank	3029	W

Component	Location	Selection condition
Compressor	Engine room	Operating condition : -20^{0}C and 45^{0}C Cooling capacity : 4639W, with 5K of subcooling at condenser outlet and 5K of superheating before the compressor
Sea water condenser	Engine room	Condenser capacity 6.2kW, sea water built, capacity depends on compressor
Evaporator	Fish hold	Stainless steel pipes of schedule 10, with nominal diameter of 25.4mm. The pipe should have circular fins with diameter 43mm at density of 200 fins/m. Total length of the evaporator coil 36m
	Bait hold	Coil type evaporator
	Slurry tank	plate coil immersible, Capacity 3.03kW, Refrigerant temperature -7^{0}C
Refrigerant		R134a
Service valve		Selected based on the liquid and gas pipe diameter. Refer drawing for the location of the valves.
Solenoid valve	Fish hold	Normally opened type valve, diameter 25.4mm
	Bait hold	Normally opened type valve, diameter 25.4mm
	Slurry tank	Normally opened type valve, diameter 25.4mm
Thermostatic expansion valve	Fish hold	-3^{0}C evaporating temperature Cooling capacity: 1051W
	Bait hold	-20^{0}C evaporating temperature Cooling capacity: 655W

	Slurry tank	-7^0C evaporating temperature Cooling capacity : 3029W
Pressure cutout		High pressure cutout should be near 11bar. Refer compressor manufacture for any adjustment.
Pressure regulating valve	Fish hold	Should regulate the pressure between -3^0C and -20^0C R134a saturation pressure
	Slurry tank	Should regulate the pressure between -7^0C and -20^0C R134a saturation pressure
Check valve	Bait hold	25.4mm diameter, solder connection
Drier	Engine room	9.5mm diameter, solder connection
Liquid line indicator		9.5 mm diameter, solder connection
Receiver		Receiver capacity : 3.8kg, R134a
Oil separator		Should be selected based on compressor capacity
Thermostats		Should operate between the range of 40^0C and -20^0C
Refrigerant pipe		Mild steel suction pipe diameter 9.5mm, discharge pipe diameter 25.4mm
Sea water side		
Sea water pump		Stainless steel impeller [1,2]
Service valve		Diameter : 19mm
Flexible joint		Diameter : 19mm
y-strainer		Diameter : 19mm
Sea water pipe		HDPE pipe diameter :19mm

1: Refer the condenser manufacture for the required flow rate of the sea water.
2: The pump head should be recalculated with the actual plant arrangement.

15m^3 fish hold with slurry tank and bait hold

Table 14: Equipment schedule for 15m^3 fish hold, 5m^3 bait hold and 6m^3 slurry tank

Boat construction condition		
Fish hold	15	m3
Bait hold	5	m3
Slurry tank	6	m3
Cooling load		
Fish hold	1417	W
Bait hold	655	W
Slurry tank	3029	W

Component	Location	Selection condition
Compressor	Engine room	Operating condition : -20^{0}C and 45^{0}C Cooling capacity : 5100W with 5K of subcooling at condenser outlet and 5K of superheating before the compressor
Sea water condenser	Engine room	Condenser capacity 6.8kW, sea water built, capacity depends on compressor
Evaporator	Fish hold	Stainless steel pipes of schedule 10, with nominal diameter of 25.4mm. The pipe should have circular fins with diameter 43mm at a space of 5mm. Total length of the evaporator coil 45m
	Bait hold	Stainless steel pipes of schedule 10, with nominal diameter of 25.4mm. The pipe should have circular fins with diameter 43mm at a space of 5mm. Total length of the evaporator coil 20m
	Slurry tank	plate coil immersible, Capacity 3.03kW, Refrigerant temperature -7^{0}C
Refrigerant		R134a
Service valve		Selected based on the liquid and gas pipe diameter
Solenoid valve	Fish hold	Normally opened type valve, diameter 25.4mm
	Bait hold	Normally opened type valve, diameter 25.4mm
	Slurry tank	Normally opened type valve, diameter 25.4mm
Thermostatic expansion valve	Fish hold	-3^{0}C evaporating temperature Cooling capacity : 1415W
	Bait hold	-20^{0}C evaporating temperature Cooling capacity : 655W
	Slurry tank	-7^{0}C evaporating temperature Cooling capacity : 3029W

Pressure cutout		High pressure cutout should be near 11bar. It may change due to selected compressor model.
Pressure regulating valve	Fish hold	Should regulate the pressure between -3^{0}C and -20^{0}C R134a saturation pressure
	Slurry tank	Should regulate the pressure between -7^{0}C and -20^{0}C R134a saturation pressure
Check valve	Bait hold	25.4mm diameter, solder connection
Drier	Engine room	9.5mm diameter, solder connection
Liquid line indicator		9.5 mm diameter, solder connection
Receiver		Receiver capacity : 3.8kg, R134a
Oil separator		Should be selected based on compressor capacity
Thermostats		Should operate between the range of 40^{0}C and -20^{0}C
Refrigerant pipe		Mild steel suction pipe diameter 9.5mm, discharge pipe diameter 25.4mm
Sea water side		
Sea water pump		Stainless steel impeller [1,2]
Service valve		Diameter : 19mm
Flexible joint		Diameter : 19mm
y-strainer		Diameter : 19mm
Sea water pipe		HDPE pipe diameter 19mm

1: Refer the condenser manufacture for the required flow rate of the sea water.
2: The pump head should be recalculated with the actual plant arrangement.

20m^3 fish hold with slurry tank and bait hold

Table 15: Equipment schedule for 20m^3 fish hold, 5m^3 bait hold and 6m^3 slurry tank

Boat construction condition		
Fish hold	20	m3
Bait hold	5	m3
Slurry tank	6	m3
Cooling load		
Fish hold	1777	W
Bait hold	655	W
Slurry tank	3029	W

Component	Location	Selection condition
Compressor	Engine room	Operating condition (-20)^{0}C and 45^{0}C Cooling capacity 5426W with 5K of subcooling at condenser outlet and 5K of superheating before the compressor
Sea water condenser	Engine room	Condenser capacity – 7.3kW, sea water built, capacity depends on compressor
Evaporator	Fish hold	Stainless steel pipes of schedule 10, with nominal diameter of 25.4mm. The pipe should have circular fins with diameter 43mm at a space of 5mm. Total length of the evaporator coil 58m
	Bait hold	Stainless steel pipes of schedule 10, with nominal diameter of 25.4mm. The pipe should have circular fins with diameter 43mm at a space of 5mm. Total length of the evaporator coil 20m
	Slurry tank	plate coil immersible, Capacity 3.03kW, Refrigerant temperature -7^{0}C
Refrigerant		R134a
Service valve		Selected based on the liquid and gas pipe diameter
Solenoid valve	Fish hold	Normally opened type valve, diameter 25.4mm
	Bait hold	Normally opened type valve, diameter 25.4mm
	Slurry tank	Normally opened type valve, diameter 25.4mm
Thermostatic expansion valve	Fish hold	-3^{0}C evaporating temperature Cooling capacity 1777W
	Bait hold	-20^{0}C evaporating temperature Cooling capacity 655
	Slurry tank	-7^{0}C evaporating temperature Cooling capacity 3029W

Pressure cutout		High pressure cutout should be near 11bar. It may change due to selected compressor model.
Pressure regulating valve	Fish hold	Should regulate the pressure between -3^{0}C and -20^{0}C R134a saturation pressure
	Slurry tank	Should regulate the pressure between -7^{0}C and -20^{0}C R134a saturation pressure
Check valve	Bait hold	25.4mm diameter, solder connection
Drier	Engine room	9.5mm diameter, solder connection
Liquid line indicator		9.5 mm diameter, solder connection
Receiver		Receiver capacity : 5.6kg, R134a
Oil separator		Should be selected based on compressor capacity
Thermostats		Should operate between the range of 40^{0}C and -20^{0}C
Refrigerant pipe		Mild steel suction pipe diameter 9.5mm, discharge pipe diameter 25.4mm
Sea water side		
Sea water pump		Stainless steel impeller [1,2]
Service valve		Diameter : 19mm
Flexible joint		Diameter : 19mm
y-strainer		Diameter : 19mm
Sea water pipe		HDPE pipe diameter :19mm

1: Refer the condenser manufacture for the required flow rate of the sea water.
2: The pump head should be recalculated with the actual plant arrangement.

25m^3 fish hold with slurry tank and bait hold

Table 16: Equipment schedule for 25m^3 fish hold, 5m^3 bait hold and 6m^3 slurry tank

Boat construction condition		
Fish hold	25	m3
Bait hold	5	m3
Slurry tank	6	m3
Cooling load		
Fish hold	2140	W
Bait hold	655	W
Slurry tank	3029	W

Component	Location	Selection condition
Compressor	Engine room	Operating condition -20^{0}C and 45^{0}C Cooling capacity 5774W with 5K of subcooling at condenser outlet and 5K of superheating before the compressor
Sea water condenser	Engine room	Condenser capacity 7.3kW, sea water built, capacity depends on compressor
Evaporator	Fish hold	Stainless steel pipes of schedule 10, with nominal diameter of 25.4mm. The pipe should have circular fins with diameter 43mm at a space of 5mm. Total length of the evaporator coil 64m
	Bait hold	Stainless steel pipes of schedule 10, with nominal diameter of 25.4mm. The pipe should have circular fins with diameter 43mm at a space of 5mm. Total length of the evaporator coil 20m
	Slurry tank	plate coil immersible, Capacity 3029kW, Refrigerant temperature -7^{0}C
Refrigerant		R134a
Service valve		Selected based on the liquid and gas pipe diameter
Solenoid valve	Fish hold	Normally opened type valve, diameter 25.4mm
	Bait hold	Normally opened type valve, diameter 25.4mm
	Slurry tank	Normally opened type valve, diameter 25.4mm
Thermostatic expansion valve	Fish hold	-3^{0}C evaporating temperature Cooling capacity 2140W
	Bait hold	-20C evaporating temperature Cooling capacity 655W
	Slurry tank	-7^{0}C evaporating temperature Cooling capacity 3029W

Pressure cutout		High pressure cutout should be near 11bar. It may change due to selected compressor model.
Pressure regulating valve	Fish hold	Should regulate the pressure between -3^{0}C and -20^{0}C R134a saturation pressure
	Slurry tank	Should regulate the pressure between -7^{0}C and -20^{0}C R134a saturation pressure
Check valve	Bait hold	25.4mm diameter, solder connection
Drier	Engine room	9.5mm diameter, solder connection
Liquid line indicator		9.5 mm diameter, solder connection
Receiver		Receiver capacity : 5.6kg, R134a
Oil separator		Should be selected based on compressor capacity
Thermostats		Should operate between the range of 40^{0}C and -20^{0}C
Refrigerant pipe		Mild steel suction pipe diameter 9.5mm, discharge pipe diameter 25.4mm
Sea water side		
Sea water pump		Stainless steel impeller [1,2]
Service valve		Diameter : 19mm
Flexible joint		Diameter : 19mm
y-strainer		Diameter : 19mm
Sea water pipe		HDPE pipe diameter :19mm

1: Refer the condenser manufacture for the required flow rate of the sea water.
2: The pump head should be recalculated with the actual plant arrangement.

30m^3 fish hold with slurry tank and bait hold

Table 17: Equipment schedule for 30m^3 fish hold, 5m^3 bait hold and 6m^3 slurry tank

Boat construction condition		
Fish hold	30	m3
Bait hold	5	m3
Slurry tank	6	m3
Cooling load		
Fish hold	2502	W
Bait hold	655	W
Slurry tank	3029	W

Component	Location	Selection condition
Compressor	Engine room	Operating condition -20^{0}C and 45^{0}C Cooling capacity 6188W with 5K of subcooling at condenser outlet and 5K of superheating before the compressor
Sea water condenser	Engine room	Condenser capacity 7.3kW, sea water built, capacity depends on compressor
Evaporator	Fish hold	Stainless steel pipes of schedule 10, with nominal diameter of 25.4mm. The pipe should have circular fins with diameter 43mm at a space of 5mm. Total length of the evaporator coil 81m
	Bait hold	Stainless steel pipes of schedule 10, with nominal diameter of 25.4mm. The pipe should have circular fins with diameter 43mm at a space of 5mm. Total length of the evaporator coil 20m
	Slurry tank	plate coil immersible, Capacity 3.03kW, Refrigerant temperature -7^{0}C
Refrigerant		R134a
Service valve		Selected based on the liquid and gas pipe diameter
Solenoid valve	Fish hold	Normally opened type valve, diameter 25.4mm
	Bait hold	Normally opened type valve, diameter 25.4mm
	Slurry tank	Normally opened type valve, diameter 25.4mm
Thermostatic expansion valve	Fish hold	-3^{0}C evaporating temperature Cooling capacity 2562W
	Bait hold	-20^{0}C evaporating temperature Cooling capacity 655W
	Slurry tank	-7^{0}C evaporating temperature Cooling capacity 3029W

Pressure cutout		High pressure cutout should be near 11bar. It may change due to selected compressor model.
Pressure regulating valve	Fish hold	Should regulate the pressure between -3^{0}C and -20^{0}C R134a saturation pressure
	Slurry tank	Should regulate the pressure between -7^{0}C and -20^{0}C R134a saturation pressure
Check valve	Bait hold	25.4mm diameter, solder connection
Drier	Engine room	9.5mm diameter, solder connection
Liquid line indicator		9.5 mm diameter, solder connection
Receiver		Receiver capacity : 5.6kg, R134a
Oil separator		Should be selected based on compressor capacity
Thermostats		Should operate between the range of 40^{0}C and -20^{0}C
Refrigerant pipe		Mild steel suction pipe diameter 9.5mm, discharge pipe diameter 25.4mm
Sea water side		
Sea water pump		Stainless steel impeller [1,2]
Service valve		Diameter : 19mm
Flexible joint		Diameter : 19mm
y-strainer		Diameter : 19mm
Sea water pipe		HDPE pipe diameter :19mm

1: Refer the condenser manufacture for the required flow rate of the sea water.
2: The pump head should be recalculated with the actual plant arrangement.

10m^3 fish hold (fish stored in ice and refrigerated fish hold)

Table 18: Equipment schedule for 10m^3 fish hold

Component	Location	Selection condition
Compressor	Engine room	Operating condition (-3)^{0}C and 45^{0}C Cooling capacity 1837W
Sea water condenser	Engine room	Condenser capacity – 3.5kW, sea water built, capacity depends on compressor
Evaporator	Fish hold	Stainless steel pipes of schedule 10, with nominal diameter of 25.4mm. The pipe should have circular fins with diameter 43mm at a space of 5mm. Total length of the evaporator coil 20m
Refrigerant		R134a
Service valve		Selected based on the liquid and gas pipe diameter
Solenoid valve	Fish hold	Normally opened type valve
Thermostatic expansion valve	Fish hold	-3^{0}C evaporating temperature Cooling capacity 1837W
Pressure cutout		High pressure cutout should be near 11bar. It may change due to selected compressor model.
Drier	Engine room	9.5mm diameter, solder connection
Liquid line indicator		9.5 mm diameter, solder connection
Receiver		Receiver capacity : 5.6kg, R134a
Oil separator		Should be selected based on compressor capacity
Thermostats		Should operate between the range of 40^{0}C and -20^{0}C
Refrigerant pipe		Mild steel suction pipe diameter 9.5mm, discharge pipe diameter 25.4mm
Sea water side		
Sea water pump	Engine room	Stainless steel impeller [1,2]
Service valve	Engine room	Diameter : 19mm
Flexible joint	Engine room	Diameter : 19mm
y-strainer	Engine room	Diameter : 19mm
Sea water pipe	Engine room	HDPE pipe diameter :19mm

1: Refer the condenser manufacture for the required flow rate of the sea water.
2: The pump head should be recalculated with the actual plant arrangement.

10m^3 refrigerated sea water

Table 19: Equipment schedule for 10m^3 RSW tank

Component	Location	Selection condition
Compressor	Engine room	Operating condition -7^{0}C and 45^{0}C Cooling capacity 3317W
Sea water condenser	Engine room	Condenser capacity 5.4kW, sea water built, capacity depends on compressor
Evaporator	RSW tank	plate coil immersible, Capacity 2.6kW, Refrigerant temperature -7^{0}C
Refrigerant		R134a
Service valve		Selected based on the liquid and gas pipe diameter
Solenoid valve	Engine room	Normally opened type valve
Thermostatic expansion valve	Engine room	-7^{0}C evaporating temperature Cooling capacity 3317W
Pressure cutout		High pressure cutout should be near 11bar. It may change due to selected compressor model.
Drier	Engine room	9.5mm diameter, solder connection
Liquid line indicator		9.5 mm diameter, solder connection
Receiver		Receiver capacity : 5.6kg, R134a
Oil separator		Should be selected based on compressor capacity
Thermostats		Should operate between the range of 40^{0}C and -7^{0}C
Refrigerant pipe		Mild steel suction pipe diameter 9.5mm, discharge pipe diameter 25.4mm
Sea water side		
Sea water pump	Engine room	Stainless steel impeller [1,2]
Service valve	Engine room	Diameter : 19mm
Flexible joint	Engine room	Diameter : 19mm
y-strainer	Engine room	Diameter : 19mm
Sea water pipe	Engine room	HDPE pipe diameter :19mm

1: Refer the condenser manufacture for the required flow rate of the sea water.
2: The pump head should be recalculated with the actual plant arrangement.

- Fish can be stored without ice but the fish quality can be lesser than the fish stored in ice. There should be sufficient amount of ice in the fish hold if it is stored with the refrigeration system. Minimum ice to fish ratio of 1.2 should be maintained for a 20 days trip and 15 days shelf life where the fish is stored in the refrigerated fish hold (Pg 27 of report). But it is recommended to store the fish and ice at a ratio 1:1.5 to have a better quality at the end of the fishing trip.
- The installing of the refrigeration system will reduce the ice melting rate and maintain the fish hold temperature at design condition throughout the whole fishing trip period.
- There is no need to use ice for the bait hold since the bait hold temperature will be -15^{0}C.

Table 20: Payback period of refrigerant plant for boats fish storing with ice at 1:1.5 ratio for 15 days in 10 fishing trips per year – with tax

Boat Size Range	System Installed	Aprox. total fish hold volume (Manufactured in Sri Lanka)	Specified Fish hold volume (m^3) for estimation of the cost	Fish storing temperature (^{0}C)	Compressor capacity (kW)	Fish storing Capacity fish to ice in ratio of 1:1.5 (kg)	Investment cost for refrigeration system without tax (Rs)	Additional Operation cost on refrigeration system with fish stored with ice per trip (Rs)	Operation cost on refrigeration system per trip (ice + refrigeration) (Rs)	Payback period for refrigerant plant with fish stored in ice in fish hold (years)
34-45 feet	RSW		12m^3	RSW tank: (-1) – 0	0.57	6000*	1,251,000	41,040		0.72
34-45 feet	Refrigerated fish hold		10m^3	Fish hold: 0.5 – 2	0.6	3000	1,487,000	32,832	62,832	1.49
34-45 feet	Refrigerated fish hold, Slurry tank, Bait hold	Fish hold: 9m^3 Bait hold: 5m^3 Slurry tank: 6m^3	Fish hold: 10m^3 Bait hold: 5m^3 Slurry tank: 6m^3	Fish hold: 0.5 – 2.0 Slurry tank: (-1) – 0 Bait hold: -15	2.48	3000	2,546,000	33,872	63,872	4.3
45-60 feet	Refrigerated fish hold, Slurry tank, Bait hold	Fish hold: 13m^3 Bait hold: 6m^3 Slurry tank: 6m^3	Fish hold: 15m^3 Bait hold: 6m^3 Slurry tank: 6m^3		2.48	4500	2,575,000	114,912	159,912	2.94
45-60 feet	Refrigerated fish hold, Slurry tank, Bait hold	Fish hold: 18m^3 Bait hold: 6m^3 Slurry tank: 6m^3	Fish hold: 20m^3 Bait hold: 6m^3 Slurry tank: 6m^3		2.96	6000	2,792,000	114,912	174,912	2.53
45-60 feet	Refrigerated fish hold, Slurry tank, Bait hold	Fish hold: 25m^3 Bait hold: 6m^3 Slurry tank: 6m^3	Fish hold: 25m^3 Bait hold: 6m^3 Slurry tank: 6m^3		2.96	7500	2,817,000	155,952	230,952	2.2
60-75 feet	Refrigerated fish hold, Slurry tank, Bait hold	Fish hold: 31m^3 Bait hold: 6m^3 Slurry tank: 6m^3	Fish hold: 30m^3 Bait hold: 6m^3 Slurry tank: 6m^3		2.96	7500	2,843,000	155,952	245,952	2.21

* For RSW tank seawater to fish ratio 1:2

- Fish can be stored without ice but the fish quality can be lesser than the fish stored in ice. There should be sufficient amount of ice in the fish hold if it is stored with the refrigeration system. Minimum ice to fish ratio of 1.2 should be maintained for a 20 days trip and 15 days shelf life where the fish is stored in the refrigerated fish hold (Pg 27 of report). But it is recommended to store the fish and ice at a ratio 1:1.5 to have a better quality at the end of the fishing trip.
- The installing of the refrigeration system will reduce the ice melting rate and maintain the fish hold temperature at design condition throughout the whole fishing trip period.
- There is no need to use ice for the bait hold since the bait hold temperature will be -15^{0}C.

Table 21: Payback period of refrigerant plant for boats fish storing with ice at 1:1.5 ratio for 15 days in 10 fishing trips per year – without tax

Boat Size Range	System Installed	Aprox. total fish hold volume (Manufactured in Sri Lanka)	Specified Fish hold volume (m^3) for estimation of the cost	Fish storing Capacity fish to ice in ratio of 1:1.5 (kg)	Fish storing temperature (^{0}C)	Compressor capacity (kW)	Investment cost for refrigeration system without tax (Rs)	Additional Operation cost on refrigeration system with fish stored with ice per trip (Rs)	Operation cost on refrigeration system per trip (ice + refrigeration) (Rs)	Payback period for refrigerant plant with fish stored in ice in fish hold (years)
34-45 feet	RSW		12m^3	6000*	RSW tank: (-1) – 0	0.57	1,087,000	41,040		0.6
34-45 feet	Refrigerated fish hold		10m^3	3000	Fish hold – 0.5 – 2	0.6	1,291,000	32,832	62,832	1.3
34-45 feet	Refrigerated fish hold, Slurry tank, Bait hold	Fish hold: 9m^3 Bait hold: 5m^3 Slurry tank: 6m^3	Fish hold: 10m^3 Bait hold: 5m^3 Slurry tank: 6m^3	3000	Fish hold: 0.5 – 2.0 Slurry tank: (-1) – 0 Bait hold: -15	2.48	2,211,000	33,872	63,872	3.8
45-60 feet	Refrigerated fish hold, Slurry tank, Bait hold	Fish hold: 13m^3 Bait hold: 6m^3 Slurry tank: 6m^3	Fish hold: 15m^3 Bait hold: 6m^3 Slurry tank: 6m^3	4500		2.48	2,236,000	114,912	159,912	2.67
45-60 feet	Refrigerated fish hold, Slurry tank, Bait hold	Fish hold: 18m^3 Bait hold: 6m^3 Slurry tank: 6m^3	Fish hold: 20m^3 Bait hold: 6m^3 Slurry tank: 6m^3	6000		2.96	2,425,000	114,912	174,912	2.32
45-60 feet	Refrigerated fish hold, Slurry tank, Bait hold	Fish hold: 25m^3 Bait hold: 6m^3 Slurry tank: 6m^3	Fish hold: 25m^3 Bait hold: 6m^3 Slurry tank: 6m^3	7500		2.96	2,446,000	155,952	230,952	2.03
60-75 feet	Refrigerated fish hold, Slurry tank, Bait hold	Fish hold: 31m^3 Bait hold: 6m^3 Slurry tank: 6m^3	Fish hold: 30m^3 Bait hold: 6m^3 Slurry tank: 6m^3	7500		2.96	2,469,000	155,952	245,952	2.04

* For RSW tank seawater to fish ratio 1:2