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COLD STORAGE CHAMBER DESIGN FOR FISHING BOATS IN THE REGION OF SALGADO, AMAZON

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Abstract. The economy of the Amazon region is heavily influenced by fishing activities, due to its large amount of rivers and aquatic species. The fish storage, cooling and freezing must be studied due to the long fishing trips, and the large number of animals captured daily. This work is a cold storage chamber design for typical Amazon boats, that uses river/sea water as secondary fluid in condensation, ensuring good operation with satisfactory results, regardless of its salinity. The project was performed considering the Thermodynamics and Heat Transfer laws. The chamber is designed to receive 800 kg per day of fish, with 50 ton as total storage capacity. The project is innovative in the refrigeration market in the north of Brazil, since the Amazon fishing boat owners do not utilize the hydraulic potential of this region in the refrigeration cycle. The results showed mean coefficient of performance (COP) values of 1.42, while the isentropic efficiency was considered 0.7.

Keywords: Cold storage chamber, refrigeration, design, Amazon fishing boats.

1. INTRODUCTION

Refrigeration in storage chambers is an essential activity in human life, since it makes possible to store food for long periods, exceeding food natural lifetime, and ensuring its quality. Storage at low temperatures avoids biological, chemical and physical reactions that could reduce this quality. The food industry must ensure security and quality on its products, so refrigeration becomes a very important market (Machado, 2000).

The Brazilian fishing market is really strong, as it generates finances and employability to many river communities, who take fishing as main activity. Figure 1 shows fishing exportation data in Brazil, from 2005 to 2016. (Brazilian Association of Shrimp Farmers, 2016).
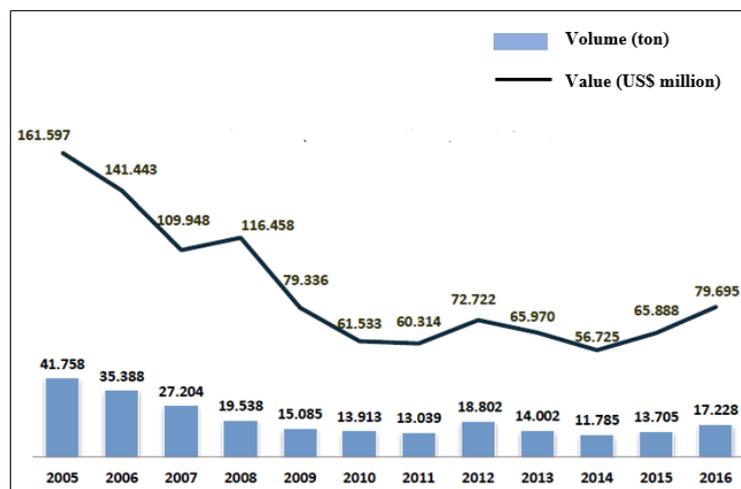

Figure 1. Fishing exports in Brazil, from 2005 to 2016. The black line is the amount (US$ million) obtained from this activity (Brazilian Association of Shrimp Farmers, 2016).

Refrigeration systems remove heat from a confined environment until it comes to the desired temperature, which depends on the application. This heat removal is possible due to the refrigeration cycle, where the working fluid flows through several equipment and accessories, undergoing some thermodynamic processes. Compressors, heat exchangers and expansion devices are the main equipment of a refrigeration system. In addition to these equipment, some appliances, such as valves, fluid storage devices, temperature and pressure sensors, etc. are selected to be implemented in the system. For this work, hydraulic pumps and an electric generator must also be installed.

The purpose of this study is to design a cold storage chamber for a fishing boat, capable to receive 800 kg of fish per day and store 50 ton of it, adapting the refrigeration system to Amazonian river environment, considering its hydraulic potential, local boundary conditions. Moreover, the goal of this project is also to improve the energy efficiency and minimize the percentage of spoiled products after a long storage period.

2. METHODOLOGY

2.1 Field survey and project parameters

In October 2016, a field survey was carried out on the fishing boat *Comandante Jonison I*, owned by the *AJ da Silva Oeiras* company, located in the city of Vigia, in the northeast of the state of Pará. Data such as volume of the boat's refrigeration chamber, daily turn of product (amount of fish captured per day), and maximum storage were collected. In addition to this case, other fishing boat projects were studied, all carried out by the *RR Oficina Costa LTDA* company, located in the city of Belém, which is partner of this project. Figure 2 is shows the port of Vigia.

Figure 2. Port of Vigia – Pará, Brazil.

From the case study, it was possible to establish design parameters that fit the reality of the fishing practice in this region, and to improve some features of the mentioned refrigeration system, such as the corrosion resistance of the equipment, the use of water– instead of air- as the condenser secondary fluid, ensuring a better energy efficiency (Incropera, 1998).

According to *American Society of Heating, Refrigeration and Air-Conditioning Engineers* (ASHRAE), initial freezing temperature of fish is about -2 °C; frozen fish should be kept at a maximum temperature of -18 °C and relative humidity 90-95%. Maintaining these parameters within the mentioned values, the life of the product is 6 to 12 months.

For a fish density of 650 kg/m³ (Charrondière, 2012), and considering that there must be enough space for air circulation and for evaporators, etc. the chamber will have 72 m³ of total volume: 12 m³ of the freezing tunnel and 60 m³ of the storage room.

The refrigerant chosen to circulate in the system was R-404a, widely found in refrigeration market and with Ozone Depletion Potential (ODP) equal to zero.

It is usual in industry that evaporation temperature stays 6 °C lower than the required temperature for the chamber. Thus, evaporation temperatures are set as -26 and -24 °C, since the freezing tunnel is kept in -20 °C and storage room is kept in -18 °C.

Figure 3 shows the designed structure of the cold storage chamber and its compartments.
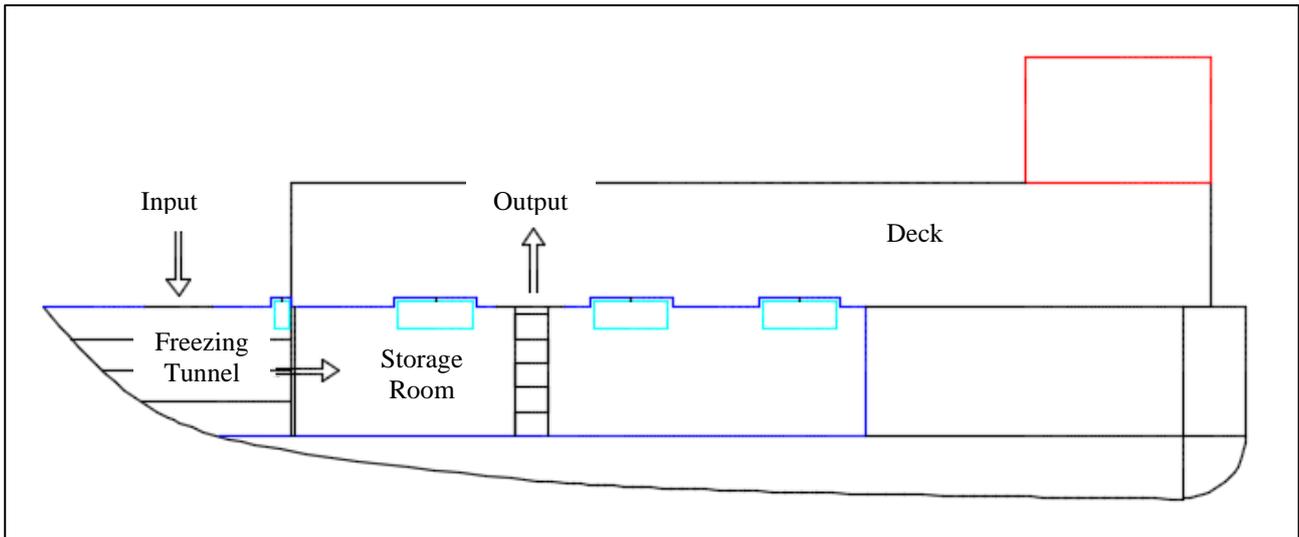
Figure 3. Flow of fish input, freezing, storage and output system.

The dark blue lines delineate the boat's cool environment. The light blue lines represent the evaporators. In red, the condensing units are shown. The fishes are placed in the chamber by the top of the freezing tunnel, and remain there for 24 hours. Then, the product is transferred to the storage room, where it will be removed at the end of the trip.

2.2 Energy efficiency of the system

The heat transfer coefficient (HTC) by natural convection varies from 2 to 25 W/m²K for gases, and from 50 to 1000 W/m²K for liquids; for forced convection, these values increase. The range for gases is from 25 to 250 W/m²K, and 50-20000 W/m²K for liquids (Incropera, 1998). Thus, using liquids in heat exchangers results an increase in the HTC; so, smaller condensers should be selected, since it is necessary less superficial area to remove energy from the refrigerant.

2.3 Equipment selection

It is necessary to analyze the materials of equipment, as these must have good corrosion resistance. Valves used in refrigeration systems are commercially found in copper, stainless steel and aluminum. Valves made of stainless steel are the best options for this type of application, and they are chosen over the others. There are some condenser models suitable for the marine environment, made of copper and nickel, ensuring less risk of corrosion. The selected compressors are made of cast iron, since it is suitable to resist the water salinity.

The main equipment and accessories of the system were selected using manufacturers' own catalogs and software; analyzing their capacity, size and material.

Centrifugal pumps are needed for feeding the condensers with river/sea water. To select pumps that fit the design, the head height of the system and its Net Positive Suction Head (NPSH) are calculated. Frictional and acceleration drop pressure are taken into account.

2.4 Thermal load calculations

The methodology used for calculating thermal load comes from thermodynamics and heat transfer laws, as the mass and energy conservation. Thermal load calculations were carried out from the product to be stored (i.e. the fish) and its amount, the external environment, the air infiltration into the chamber, the electric lighting in the chamber, and, finally, the circulation of people inside the chamber. The chamber is divided into two spaces: the freezing tunnel and the storage room. These environments require different temperatures and internal volumes, therefore the calculation of the cooling capacity, insulation thickness and internal volume were done for each space separately. Table 1 shows Eqs. (1) to (8), that are used to calculate the thermal load from the influences taken into account, previously mentioned.

Table 1. Equations for thermal load of product load, air infiltration, electric lighting and people circulation, for freezing tunnel and storage room.

Influence	Freezing tunnel (1)	Eq.	Storage room (2)	Eq.
Product load (pl)	$\dot{Q}_{pl1}=m_d[cp_1(T_{in}-T_f)+h_{lc}+cp_2(T_c-T_s)]$	(1)	$\dot{Q}_{pl2}=m_tcp_2\Delta T$	(2)
Air infiltration (ai)	$\dot{Q}_{ai1}=24V_{ft}\Delta H'ACH$	(3)	$\dot{Q}_{ai2}=24V_{sr}\Delta H'ACH$	(4)
Electric lighting (el)	$\dot{Q}_{el1}=3.6A\tau q_l$	(5)	$\dot{Q}_{el2}=3.6A\tau q_l$	(6)
People circulation (pc)	$\dot{Q}_{pc1}=3.6(272+6T_{int})\tau'n$	(7)	$\dot{Q}_{pc2}=3.6(272+6T_{int})\tau'n$	(8)

Where:
- $\dot{Q}$ is used for thermal load and the subscripts denote each influence and place (kJ);
- m_d and m_t are the daily turn of product and total amount of product (kg), respectively;
- cp_1 and cp_2 are the specific heat before and after freezing (kJ/kg°C), respectively;
- T_{in}, T_f and T_s are the product inlet temperature, freezing temperature and storage temperature (°C), respectively;
- ΔT and T_{int} are the temperature difference due to product handling and transport from freezing tunnel to storage room, and internal chamber temperature (°C), respectively;
- h_{lc} is latent heat of freezing of product (kJ/kg°C);
- $\Delta H'$ is heat per volume of air entering the chamber (kJ/m³);
- V_{ft} and V_{sr} are the volume of freezing tunnel and storage room (m³), respectively;
- ACH is the value of air change per hour (h⁻¹);
- τ and τ' are time of lamp lit in the chamber (hours/day) and length of stay of people inside the chamber (hours/day), respectively;
- A is the area of the chamber (m²);
- q_l is the power dissipated by the lighting system (W/m²);
- n is the number of people entering in the chamber.

External environment thermal load is taken into account in Eq. (10), where the thermal resistance is determined.

2.5 Wall materials and thickness

Amazon fishing boats are usually made of wood. However, it is necessary to insulate the chamber with a maximum heat flux of 13.95 W/m² (Pirani, 2005). In order to well insulate the chamber and not overload the mass of the boat, a polyurethane (PUR) insulation will be inserted into the walls, creating an inner layer of insulation.

Considering heat transfer by conduction and convection, heat flux values inside and outside the chamber were determined according to some manufacturers' catalogs and the literature.

To determine the wall thickness, Eqs. (9) and (10) are used.

$$q=\frac{\Delta T}{R_T} \tag{9}$$

$$R_T=\frac{1}{h_{ext}}+\sum_{1}^{n}\frac{L_n}{k_n}+\frac{1}{h_{int}} \tag{10}$$

where q, ΔT, R_T, h_{ext}, h_{int}, k_n and L_n are the heat flux (W/m²), temperature difference corrected between the outside and the chamber (°C), total thermal resistance (m² °C/W), external and internal HTC by convection (W/m² °C), n-wall thermal conductivity (W/m°C), and n-wall thickness (m), respectively.

3. RESULTS AND DISCUSSION

Applying the equations of Tab. 1, it is possible to determine the total thermal load of the chamber. Table 2 shows the results for thermal load due to each influence, including load coming from external environment through the walls, floor and ceiling.

Table 2. Partial and total thermal load for freezing tunnel and storage room of cooling chamber

Influence	Freezing tunnel	Storage room
Product load	$\dot{Q}_{pl1}=3.136\ kW$	$\dot{Q}_{pl2}=2.615\ kW$
Air infiltration	$\dot{Q}_{ai1}=0.461\ kW$	$\dot{Q}_{ai2}=0.919\ kW$
Electric lighting	$\dot{Q}_{el1}=0.022\ kW$	$\dot{Q}_{el2}=0.045\ kW$
People circulation	$\dot{Q}_{pc1}=0.020\ kW$	$\dot{Q}_{pc2}=0.020\ kW$
External environment	$\dot{Q}_{ee1}=0.362\ kW$	$\dot{Q}_{ee2}=1.562\ kW$
Total thermal load	$\dot{Q}_{total1}=4.001\ kW$	$\dot{Q}_{total2}=5.161\ kW$

The points in the refrigeration cycle of the systems were determined using *CoolPack*, part of *Engineering Equation Solver* software; considering isentropic efficiency 70%, superheating degree 5 K and subcooling degree equal to 2 K. Figures 5 and 6 show plot diagrams for the freezing tunnel and storage room refrigerating cycles.

Main equipment chosen for the chamber are:
- Freezing tunnel: 1 low profile forced-air evaporator (refrigerating capacity: 4.40 kW and flow rate 4273 m³/h); 1 semi-hermetic reciprocating compressor (absorbed power: 3.09 kW); 1 shell and tube horizontal condenser (sea water resistant, 2 passes, 7.75 kW capacity); 1 thermostatic expansion valve with external equalization (nominal capacity: 5.412 kW, capillary tube 1.5 m and maximum working pressure 34 bar); 1 centrifugal pump (0.18 kW of power).
- Storage room: 2 double-forced air evaporators (refrigerating capacity 2.66 kW, flow rate 4536 m³/h); 1 semi-hermetic reciprocating compressor (absorbed power: 3.09 kW); 1 shell and tube horizontal condenser (sea water resistant, 4 passes, 9.46 kW capacity); 1 thermostatic expansion valve with external equalization (nominal capacity: 1.518 kW, capillary tube 1.5 m and maximum working pressure 34 bar); 1 centrifugal pump (0.18 kW of power).

For a better visualization of the arrangement of the equipment and accessories installed in the refrigeration system, a two-dimensional scheme of the equipment installation in the cold storage chamber was designed.
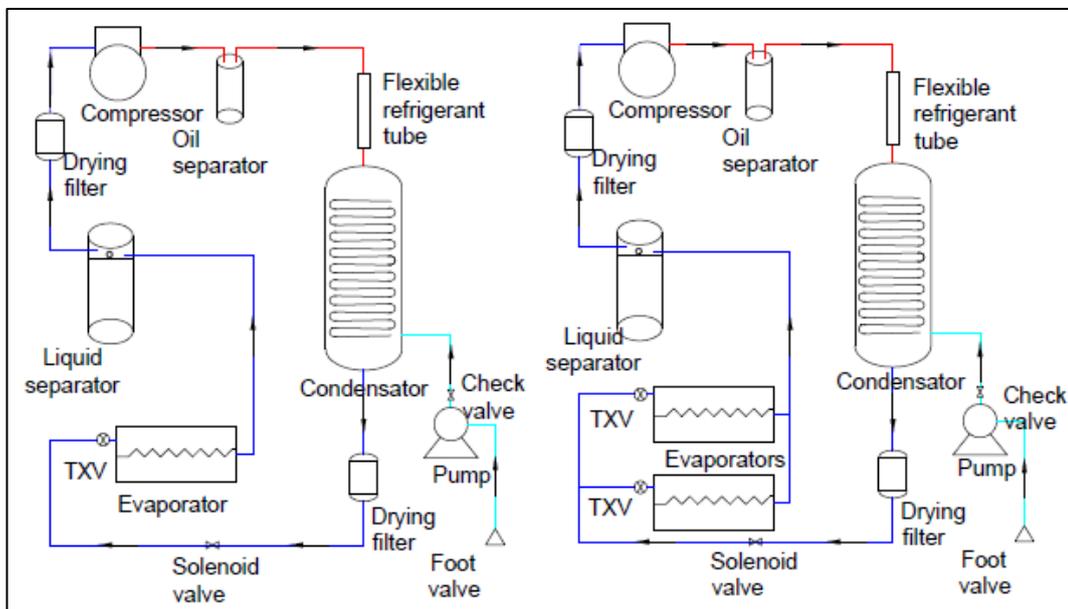

Figure 4. Circuit of the freezing tunnel (left) and the storage room (right) refrigeration systems.

COP calculated in *CoolPack* is 1.82 (freezing tunnel) and 1.72 (storage room). However, this value may vary due to an electric generator installed to feed electric equipment and accessories of the system. According to calculations adding all power requiring machines, COP is 1.42.
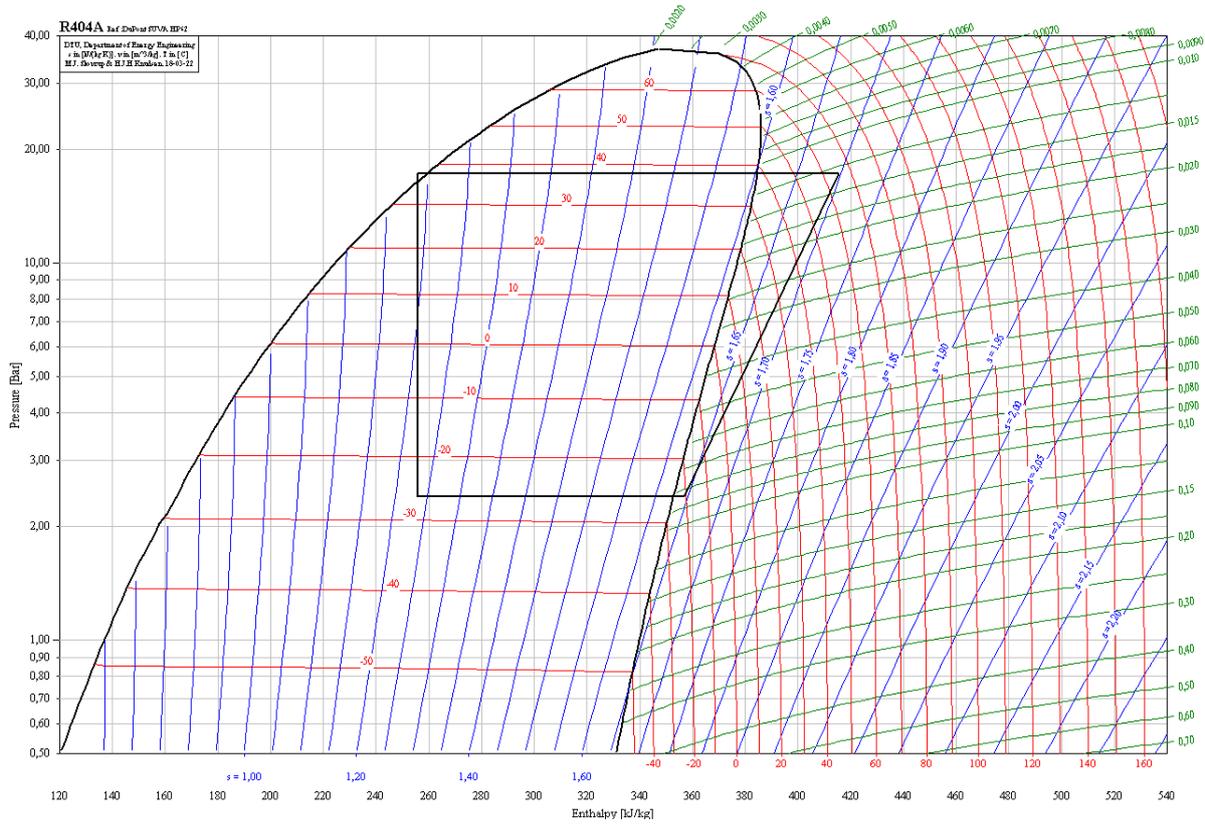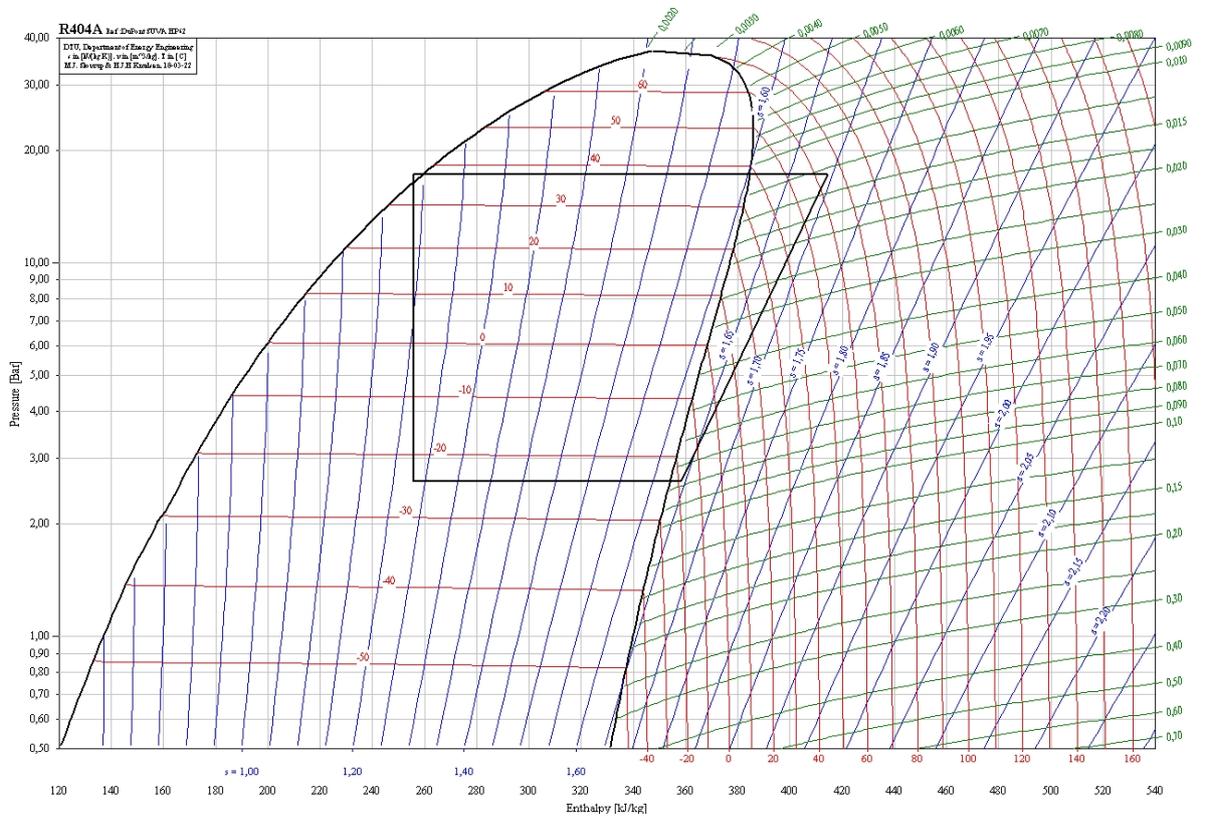
Figure 5. Freezing tunnel cycle.

Figure 6. Storage room cycle.

The lengths of the lines were designed from the positioning of the condenser unit and accessories in the design sketch, drawn in *Autocad ®*. Figure 7 shows the scheme of the cold storage chamber.
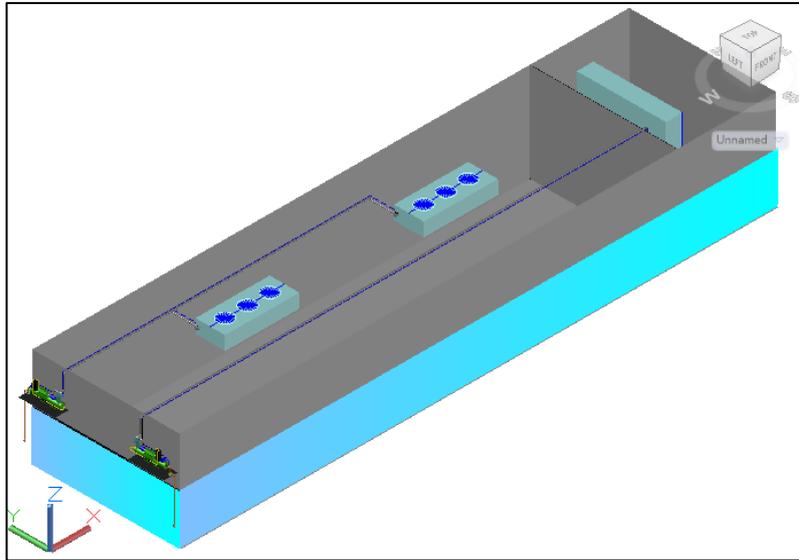

Figure 7. Isometric scheme of the cold storage chamber.

The lengths of the lines are shown in table 3.

Table 3. Lengths of suction, discharge, liquid and pump lines of the cold storage chamber design.

	Freezing tunnel (m)	Storage room (m)
Suction line	11.04	7.835
Discharge line	1.189	1.189
Liquid line	11.18	8.290
Pumps line	0.796	0.796

4. CONCLUSIONS

Water condensation system takes advantage in size and energy efficiency, moreover it uses the hydraulic potential of Amazon rivers. COP value for the designed system is 1.42. Some studies may still be made for the improvement of this project, as the study of new materials for insulation, study of humidity control in the chamber, use of renewable energy (solar and wind, for example), water desalination study for use of less complex refrigeration equipment, etc. The project budget was not made, but it would be interesting compare the initial costs of this project with some already existing ones, which secondary fluid in condensation is air.

5. AKNOWNLEDGMENTS

6. REFERENCES

AutoCAD 360 for Windows. Version 2.1. © Autodesk Inc, 2018.

Alé, J. Pump systems. Department of Mechanical and Mecatronic Engineering. PUCRGS. 2010.

American Society Of Heating, Refrigeration And Air-Conditioning. Refrigeration: Commodity Storage Requirements. Handbook. 2006.

American Society Of Heating, Refrigeration And Air-Conditioning. Refrigeration: Thermal Properties of Foods. Handbook. 2006.

Brazilian Association Of Shrimp Breeders. Commercial balance of fish n°5. 2016.

Charrondiere, R. et al. Density Database version 2.0. Food and Agriculture Organization of the United Nations/International Network of Food Data Systems. Rome, Italy. 2012.

CoolPack version 1.5. Refrigeration Utilities. IPU and Department of Mechanical Engineering. Technical University of Denmark. 2012.

Incropera, F. P. Dewitt, D. P. Fundamentals of Heat and Mass Transfer. 4th ed. Rio de Janeiro, LTC, 1998. 494 p.

Machado, R. L. P. Good Transportation Practices In The Food Industry. Rio de Janeiro: EMBRAPA, 2000. 28p.

Martinez, I. Heat and mass convection. 2016.

Mcdonald, A. G. Magande, H. L. Appendix C: Heat Exchanger Design. Wiley Online Library. 2012.

Peng, W. P. Fundamentals of Turbomachinery. Wiley. 384 p. 2007.

Pirani, Marcelo J. Part I: Refrigeration. Department of Mechanical Engineering, Federal University of Bahia. 2005.

Stoecker, W. F. Jabardo, J. M. S. Industrial Refrigeration. 2nd ed. São Paulo, Blucher, 371 p. 2002.

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