Engineering tools and technologies for energy efficient fish processing operations

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Fisheries comprise a major economic activity within complex interactions between human beings and water - 'the first among equals' of the natural resources (Ahmed, 1992). Fisheries data assembled by the Food and Agriculture Organization (FAO) suggest that global marine fisheries catches increased to 86 million tonnes in 1996, then slightly declined. In the past three decades, employment in fisheries and aquaculture has grown at a higher rate than the growth of world population. The fishery engineering is evolving as an important domain in view of depleting stocks on both pre and post-harvest scenarios. It will also aid in fish processing technologies, optimizing energy and water use in seafood industries, mitigating climate change related issues and reducing carbon footprint. It is important to explore novel ways to obtain, quantify, and integrate industry responses to declining fishing stocks and increasing management regulations into fishery- and ecosystem-based management advice. The technological interventions help to reduce the wastage of fish, which is otherwise a highly perishable commodity by preservation technologies and converting it into value added products with higher shelf life. Use of appropriate technologies along the fish value chain will help in producing better quality products and fetch more markets and higher price.

Major areas of technological interventions in the field of fishery engineering cover design and development of fish processing equipment and machineries, energy efficient and eco-friendly solar fish dryers, fuel efficient fishing vessels and fiberglass canoes, indigenous electronic instruments for application in harvest and post-harvest technology of fish, quality improvement of Indian fishing fleet and energy and water optimization techniques for fish processing industries. Focused areas include development of cost effective solar dryers with LPG, biomass, Infra-Red or electrical back-up heating systems, fish descaling machines, Fish freshness sensor etc.

1. Technologies for fish processing and value addition

Post-harvesting processing of fish are important to reduce wastage, increase shelf-life, add more value to the products and ensure higher returns. The major engineering interventions for fish post-harvest operations, processing and value addition are given below:

1.1 Solar dryers

Out of total catch 30-40 % of fish is dried or processed for export and local consumption. Sun drying (open air drying) is the traditional method employed in most parts of the state to dry fishery products. It denotes the exposure of a commodity to direct solar radiation and the convective power of the natural wind. This form of energy is free,

renewable and abundant in any part of the world especially in tropical countries. Also it offers a cheap method of drying but often results in inferior quality of product due to its dependence of weather conditions and vulnerability to the attack of dust, dirts, rains, insects, pests, and microorganisms. Solar drying is an alternative which offers numerous advantages over the traditional method and environmentally friendly and economically viable in the developing countries. In solar drying, a structure, often of very simple construction, is used to enhance the effect of the solar radiation. Compared to the sun drying, solar dryers can generate higher air temperatures and consequential lower relative humidity, which are conducive to improved drying rates and lower final moisture content of the final products. However, there exist some problems associated with solar drying i.e. reliability of solar radiation during rainy period or cloudy days and its unavailability during night time. To overcome this limitation, an auxiliary heat source and forced convection system are recommended for assuring reliability and better control, respectively.

In a hybrid solar drying system, drying can be continued during off-sunshine hours by utilizing backup heat source and stored heat energy of daytime sunshine. In this way, drying becomes continuous process and the product is saved from possible deterioration by microbial infestation. These types of Hybrid solar dryers find useful applications in developing countries where the conventional energy sources are either scarce or expensive and the heat generating capacity of the solar system alone is not sufficient. Further, to assist the drying process (forced convection) in a hybrid dryer, a small blower is attached in between solar collector and drying chamber or inside the drying chamber which is powered by solar PV panels installed on drying chamber. Moreover, power from PV panels can be used for street lighting purposes. In addition, if the proposed setup is not used for drying purpose (kept idle), then the same can be used to draw hot water for domestic use. Therefore, in a single set up it is envisaged to have multiple utilities i.e. drying of fish, hot water and electricity generation.

Design of solar dryer varies from simple direct dryers to more complex hybrid designs. Hybrid model solar dryers are having LPG, biogas, biomass or electricity as an alternate back up heating source for continuous hygienic drying of fish even under unfavourable weather conditions. ICAR-CIFT has developed different models and capacities of solar dryers for hygienic drying of fish. The capacity of these hybrid solar dryers varies from 6 to 110 m^2 of tray spreading area for drying of various quantities of fish varying from 10 kg to 500 kg.

The labour requirement is considerably reduced compared to open sun drying in beaches / coir mats because of the elimination of cleaning process due to sand and dust contamination. Re-handling process like spreading, sorting and storing because of non-drying or partial drying due to unfavourable weather conditions and spoilage due to rain is also not required. The drying time is reduced considerably with improved product quality. Improved shelf life and value addition of the product fetches higher income for the fisher folk. The eco-friendly solar drying system reduces fuel consumption and can have a significant impact on energy conservation.

ICAR-CIFT design includes small capacity dryers like solar tent dryers, natural convection dryers *etc.* which will be useful to dry fish hygienically during sunny days. Solar

tunnel dryers, solar fish dryers with alternate electrical back up (SDE-10, SDE-20 and SDE-50) and solar fish dryers with fire wood or biomass alternate back up heating system (SDF-20, SDF-50) *etc.* can be efficiently used to dry fish using renewable solar energy which is abundantly and freely available. The details of solar dryers with different backup systems are given below:

a) Solar Dryer with LPG back-up: ICAR-CIFT designed and developed a novel system for drying of fish using solar energy supported by environment friendly LPG back up (Fig.1). In this dryer during sunny days fish will be dried using solar energy and when solar radiation is not sufficient during cloudy/ rainy days, LPG back up heating system will be automatically actuated to supplement the heat requirement. In the solar fish dryer with LPG back up heating system, water is heated with the help of solar vacuum tube collectors installed on the roof of the dryer and circulated through heat exchangers provided in the PUF insulated stainless steel drying chamber loaded with fish. Thus continuous drying is possible in this system without spoilage of the highly perishable commodity to obtain a good quality dried product.

This dryer is ideal for drying of fish, fruits, vegetables, spices and agro products without changing its colour and flavour. It helps to dry the products faster than open drying in the sun, by keeping the physico-chemical qualities like colour, taste and aroma of the dried food intact and with higher conservation of nutritional value. Programmable logic Controller (PLC) system can be incorporated for automatic control of temperature, humidity and drying time. Solar drying reduces fuel consumption and can have a significant impact on energy conservation.

Fig.1. CIFT Solar-LPG Dryer

b) Solar dryer with Electrical back-up: Effective solar drying can be achieved by harnessing solar energy by specially designed solar air heating panels and proper circulation of the hot air across the SS trays loaded with fish (Fig.2). Food grade stainless steel is used for the fabrication of chamber and perforated trays which enable drying of fish in a hygienic manner. Since the drying chamber is closed, there is less chance of

material spoilage by external factors. An alternate electrical back-up heating system under controlled temperature conditions enables the drying to continue even under unfavourable weather conditions like rain, cloud, non-sunny days and in night hours, so that the bacterial spoilage due to partial drying will not occur. Improved shelf life and value addition of the product fetches higher income for the fisher folk. The eco-friendly solar drying system reduces fuel consumption and can have a significant impact on energy conservation.

Fig.2 CIFT Solar-Electric Dryer

c) Solar-Biomass Hybrid dryer: A dryer working completely on renewable energy was designed and developed for eco- friendly operation. Solar Biomass Hybrid Dryer consists of well insulated and efficient solar air-heating panels, drying chamber, SS mesh trays, photo-voltaic cells, fans and biomass heating system (Fig.3). Hot air is generated by virtue of solar energy inside the heating panels and passed into the drying chamber. Continuous flow of hot air is maintained with the help of PhotoVoltaic cells and fans to enable drying process. During cloudy days when sufficient solar energy is not available to maintain required temperature within the dryer, an alternate biomass heating system is manually actuated. Thus a fully green technology for fish drying is achieved by this.

Fig.3 CIFT Solar-Biomass Dryer

d) Solar Tunnel dryer: Solar tunnel dryer utilizes solar energy as the only source of heat for drying of the products. Heat absorbing area of 8 m^2 is made of polycarbonate sheet (Fig.4). Products to be dried are placed on nylon trays of dimension 0.8X0.4 m. The dimensions of the whole drying unit is 2.21X2.10X0.60 m. The capacity of the dryer is 5 kg. Drying takes place by convection of hot air within the drying chamber. Apart from fish, this dryer is also suitable for other agricultural products like fruits, vegetables and spices.

Fig.4 CIFT Solar-Tunnel Dryer

e) Solar Cabinet dryer with electrical back-up: This offers a green technology supplemented by electrical back up in case of lacunae in solar radiation. The dryer consists of four drying chambers with nine trays in each chamber (Fig.5). The trays made of food grade stainless steel are stacked one over the other with a spacing of 10 cm. The perforated trays accomplish a through flow drying pattern within the dryer which enhances drying rates. Solar flat plate collectors with an area of 7 m^2 transmit solar energy to the air flowing through the collector which is then directed to the drying chamber. The capacity of the dryer is 40 kg. Electrical back up comes into role once the desired temperature is not attained for the drying process, particularly during rainy or cloudy days.

Fig.5. CIFT Solar-Cabinet Dryer with Electrical back-up

f) Infrared drying – CIFT has recently developed an Infra Red (IR) dryer heat transfer is happening by radiation between a hot element (infrared lamps) and a material (to be dried). Thermal radiation is considered to be infrared in the electromagnetic spectrum between the wavelength of 0.78 µm and 1000 µm. Infrared emitters offer efficient heat and much more advantages compared to other conventional heat technologies:

- No direct contact with the product High drying/heating rate
- Infrared radiation can be focused where it is needed in a defined time,
- Cost savings thanks to high overall efficiency and optimal infrared heaters lifetime.

1.2 Fish Descaling Machines

a) Fish descaling machine with variable drum speed: Fish descaling machine is designed and fabricated for removing the scales of fish easily. This equipment can remove scales from almost all types/sizes/ species of fish ranging from marine to freshwater species like Sardine, Tilapia to Rohu. The machine is made of SS 304 and has 10 kg capacity. It contains a 1.5 HP induction motor and a Variable Frequency Drive (VFD) to vary the speed of the drum depending on the variety of the fish loaded. The drum is made of perforated SS 304 sheet fitted in a strong SS Frame. Water inlet facility is provided in the drum for easy removal of the scales from the drum so that area of contact to the surface will be more for removal of scales. The water outlet is also provided to remove scales and water from the machine. An Electronic RPM meter was attached with the descaling machine which directly displays the RPM of the drum. Speed of the drum is a factor influencing the efficiency. The machine takes only 3-5 minutes to clean 10 kg fish depending on the size.

Fig.6 Fish descaling machine with variable drum speed

b) Fish **descaling machine with fixed drum speed- table top:** Fish descaling machine is designed and fabricated for removing the scales of fish easily. This equipment can remove scales from almost all types/sizes/ species of fish ranging from marine to freshwater species like Sardine, Tilapia to Rohu. This machine is made of SS 304 and has 5 kg capacity. It contains a 0.5 HP AC motor with proper belt reduction mechanism to achieve required drum speed of 20-30 rpm. Body is fabricated in dismantling type one-inch square SS tube with a suitable covering in the electrical parts. The drum is made of perforated SS sheet fitted in a strong SS Frame having suitable projections to remove the scale and provided with a leak proof door with suitable lock.

c) Fish descaling machine hand operated: Fish descaling machine is designed and fabricated for removing the scales of fish easily. This equipment can remove scales from almost all types/sizes/ species of fish ranging from marine to freshwater species like Sardine, Tilapia to Rohu (Fig.7). This machine is made of SS 304 and has 5 kg capacity. Body is fabricated in dismantling type 1 inch square SS tube. The drum of 255.5 mm diameter and 270 mm length is made of perforated SS sheet fitted in a strong SS Frame having suitable projections to remove the scale and provided with a leak proof door with suitable lock. A pedal is fitted in the side to rotate the drum manually.

Fig.7 Fish descaling machine hand operated

1.3 Fish meat bone separator:

A Fish Meat Bone Separator with variable frequency drive (VFD) to separate pin bones from freshwater fish was designed and developed. This can be used at a range of 5-100 rpm. With a unique belt tighten system developed; the new machine can be easily adapted to any species and need not be customised for specimen during the design stage. In existing imported models, only two speeds are possible which restricts the yield efficiency in a single span operation and also limits easy switching of the system for utilising specimen other than for which the yield has been originally customised. The meat yield of this machine was about 60% against 35% in imported models. Capacity of the machine is 100kg/hour.

1.4 Modern Hygienic Mobile fish vending kiosk:

Most of the fisher folk across India sell fish in an open basket without any hygienic practices. The fish is kept in an open bag or container, it loses its freshness. They use ice purchased at high cost for temporary preservation and at the end of the day, if the fish is not sold, they give it at a low rate to customers with little or no profit. More over fish gets contaminated under unhygienic handling practices. The fish vending persons, especially women folk find it difficult to carry the fish as head load and subsequently sell it in the local markets or consumer doorsteps. In this context, the ICAR-CIFT have designed and developed a mobile fish vending kiosk for selling fish in the closed chilled chamber under hygienic conditions at consumer doorstep (Fig.8).

Fig.8 Refrigeration enabled Mobile Fish vending kiosk

The major advantages of the new Kiosk are as follows:

- The mobile kiosk was designed considering the maximum weight that a man pulls on rickshaw.

- The mobile unit is mounted on frame with wheels at the bottom. The kiosk can carry 100kg fish with 20kg under chilled storage display in glass chamber and remaining in insulated ice box (developed by CIFT).
- The main components of the kiosk are fish storage & display chilled glass chamber, hand operated descaling machine and fish dressing deck with wash basin, water tank, cutting tool, waste collection chamber and working space.
- The vending unit has been fabricated mainly using stainless steel (SS 304 Food Grade) and frame and supports are made with MS and GI sheets.
- The kiosk main part *i.e* chilling unit & display for fish storage which was envisaged to power by solar energy through solar PV cells,however presently powered by AC current.
- The stored fish is covered with a transparent glass cover through which consumers can see the fish and select according to their choice of purchase.
- Kiosk is attached with hand operated descaling machine for removal of scales. The fish coming out of descaler is free of scales, dirt or slime.
- It also reduces human drudgery and avoids cross contamination, consumes less time. Fish dressing deck with wash basin also designed conveniently to prepare fresh clean fish under hygienic conditions.

Chilling of fish using electricity/PV cells or by adding large quantity of ice adds to cost to the selling price. Since this technology has well insulated storage space for fish with provisions for refrigeration, it reduces the ice melting rate and its cost, thereby reducing the selling price. The unit also extends the keeping quality of fish for 4- 5 days and increases marginal benefit to fish vendors. It also helps change the practice of unhygienic handling and marketing of fish.

1.5 Electronics and Instrumentation:

ICAR-CIFT identified the vast scope of electronics and instrumentation for fisheries technological investigations and started research and development activities. This resulted in a series of instruments for systematic monitoring, analysis and assessment of the marine environment including the performance of the machinery used for harvesting the resources and post-harvest technology. Basic technologies developed in ICAR-CIFT include more than five dozens of electronic instruments with fully indigenous technology and more than 50 sensors with novel features and designs. The notable achievement is the development of indigenous sensors, which are rugged to withstand hostile marine environment and enable us to monitor field data from remote areas. The total instrumentation is built up around these sensors, with required electronics, new signal processors and other peripherals for solid-state data storing, compatibility to PC, wireless transmission to distant points *etc.*

Some of the instruments, which has got great attention and acceptance are as follows: environmental data acquisition system, freezer temperature monitor, salinity temperature depth meter, hydro meteorological data acquisition system, warp load meter, solar radiation monitor and integrator, ship borne data acquisition system, water level recorder, ocean current meter, remote operated soil moisture meter, water activity meter, rheometer and micro algae concentration monitor. Since the instruments are designed to

be compatible with computers and solid-state memory module, the information can be stored for long duration and retrieved at our convenience.

By effective use of efficient and appropriate engineering technologies which are cost-effective, adaptable and environmentally friendly, the fishermen community as well as seafood industry can reduce the harvest and post-harvest expenses and losses, add more value to the products, ensure better fish value chain dynamics and thereby obtain more income. The use of green and clean technologies also ensures less carbon and water footprints.

2. Commercialization and Agri-Business Incubation

Agri-Business Incubators (ABI) open new entry points in the agricultural value chains, which in turn can use to access new markets. They afford leverage through these entry points to accelerate agricultural development and offer the unique potential to develop small and medium-sized enterprises (SME's) which can add value along these chains in ways which other development tools do not offer. There is no single "right way" to perform agribusiness incubation. Rather the work of agribusiness incubation depends on the state of development of the agribusiness ecosystem and changes over time as that ecosystem matures and develops. In its earliest phases, incubators demonstrate the viability of new business models and look to create and capture additional value from primary agricultural products. In underdeveloped agricultural economies, incubators help by strengthening and facilitating linkages between enterprises and new commercial opportunities. They open new windows on technologies appropriate to agribusiness enterprises and help agricultural enterprises discover new, potentially more competitive ways of doing business. In subsequent phases of development, incubators operate as network facilitators: they link specialized service providers to agribusinesses and link separate agribusinesses to one another. Finally, in a more advanced state of business development, incubators operate as conduits for the exchange of technology, products, inputs and management methods across national borders.

A more pragmatic system for business incubation and promoting start-up companies with respect to agricultural technologies have been evolved in recent times within the ICAR-CIFT. The Agri-Business Incubation (ABI) center along with Institute Technology Management Unit (ITMU) seeks to provide business consulting services to agriculture-related businesses and helps to develop a strategic business plan. ABIs facilities for incubation of new business ideas based on new agricultural technologies by providing cheap space, facilities and required information and research inputs. The Agribusiness Incubator Program also seeks to provide business consulting services to agriculture-related businesses and helps to develop a strategic business plan.

The Engineering Division of ICAR-CIFT has commercialized its technologies like solar fish dryers, fish descaling machines, refrigeration enabled fish vending machines etc through the ABI. On non-exclusive license mode, 10 firms have been empanelled to manufacture/fabricate machineries as per CIFT design and commercialize it to needed customers by paying royalty to the institute. In the financial year 2018-19 itself, 15 entrepreneurs have taken up Solar fish drying technology and three start-ups came up by

establishing CIFT designed fish vending kiosks. Five fish descaling machines were also successfully handed over to sea-food industries located both in Andhra Pradesh and Kerala. Apart from these, 10 numbers of fish dryers of 10 kg capacity were distributed among women SHG groups located in Kerala, Manipur and Assam for demonstration purposes. Furthermore, 28 incubatees (one physical and two virtual) have already registered under ABI in the current year for using engineering technologies. Apart from these, an MOU was signed between ICAR-CIFT and Society for Assistance to Fisherwomen (SAF), Directorate of Fisheries, Govt of Kerala, for fabrication and installation of 20 numbers of Refrigerated fish vending kiosk for the benefit of fisher women SHGs.

3. Energy and Water Use Optimization in Seafood Processing Industry

Energy consumption in seafood or any food processing plant depends largely upon the age and scale of the plant, level of automation, intensity and type of processing operations, plant management practices, plant layout and organization, equipment efficiency and range of products manufactured. The cooking and canning are very energy-intensive processes, whereas the filleting consumes less energy. Thermal energy, in the form of steam and hot water, is used for cleaning, heating, sterilizing and for rendering. The operation of machinery, refrigeration, ventilation, lighting and production of compressed air uses high amount of electricity (Fig. 9). Similarly, seafood industry consumes significant amounts of water in each stage of processing (Fig.10). It also produces a large quantity of waste water. The CIFT have installed energy meters in three industries within Kochi cluster for monitoring the daily energy consumption pattern.

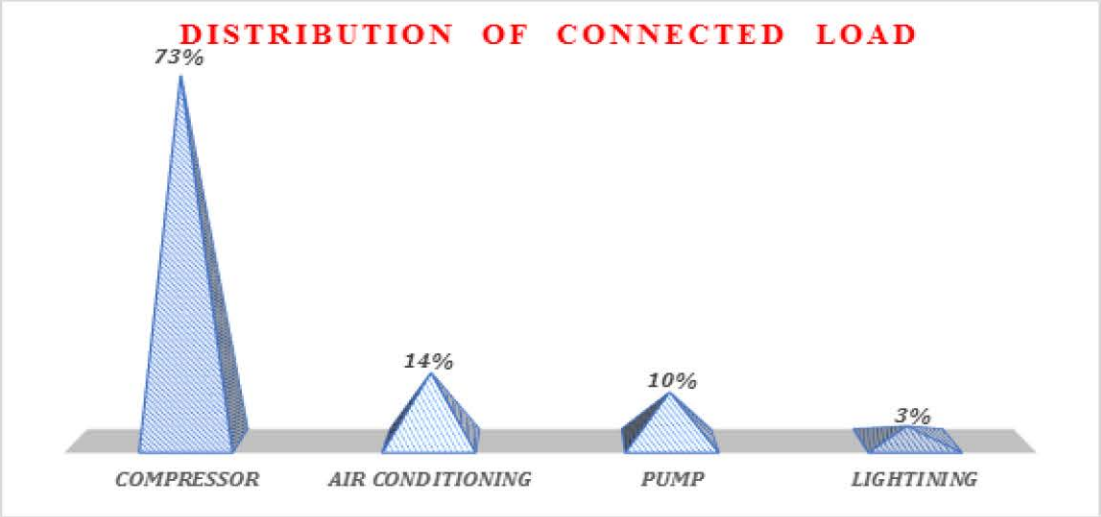

Fig. 9 Distribution of connected load in seafood processing units of the Kochi cluster (Source: BEE, 2015)

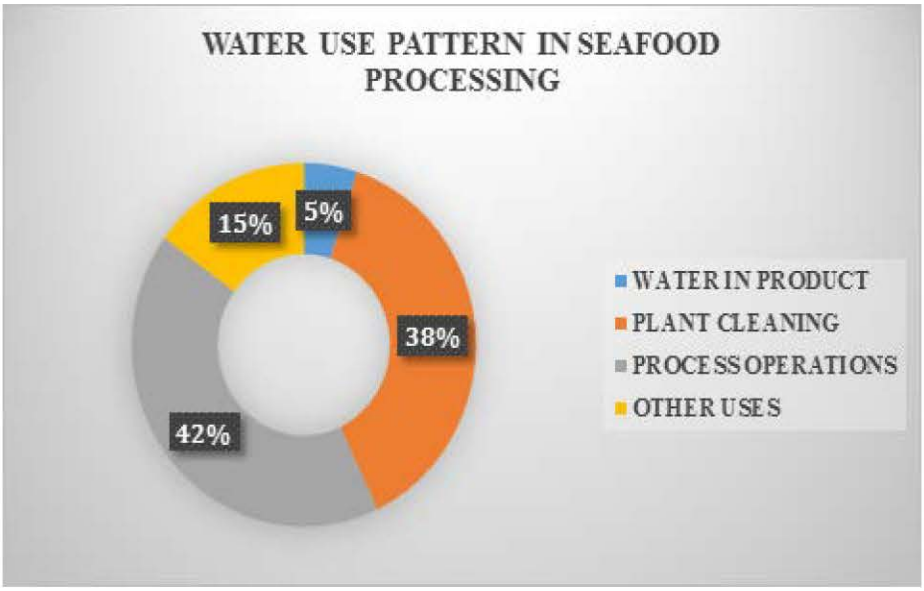

Fig. 10 Water use pattern in a typical seafood processing unit. (Source: BIM, 2017)

3.1 Energy optimization methodologies

Energy optimization methodologies can be broadly classified in the following six categories:

i ***Automation of existing process line:*** Energy wastage in the seafood industry can be greatly reduced by precisely controlling the working of all equipment in the process line. Merely by controlling the timely switching on and off equipment can save a lot of energy, which can be practically impossible in manual operation.

ii ***Sensitize the labor about energy conservation:*** The operation level labor's attitude and behavior have a major impact on the energy optimization point of view. Awareness among the labors regarding energy wastage that can occur due to mere negligence or ignorance has to be created. Instructions can be given to them regarding reducing energy wastage, for example, the chill room doors should be closed immediately after loading or unloading to prevent temperature rise inside etc.

iii ***Equipment upgrade:*** Existing equipment should be monitored for their efficient working through periodic repair and maintenance. Regular servicing and if required replacement of worn out parts should be done. This can actually improve the processing efficiency of the equipment and in turn of the whole plant. The usage of plate freezers considerably reduces the energy consumption in seafood freezing.

iv ***Replacement of out-dated equipment and technology:*** Latest technologies and sophisticated and energy saving equipment can be explored to reduce the energy consumption of plant. For example, reciprocating and centrifugal type compressors can be replaced by a screw compressor, which can give higher processing efficiency or Replacement of existing V-belt drive with synthetic energy efficient flat belt drive in the compressor motor. The direct contact water condensers can be replaced by Evapco type condensers. Installation of Variable Frequency Drive (VFD) for condenser

water Pumps. These are relatively capital intensive method but high reduction in energy consumption can be obtained.

v ***Energy auditing and budgeting:*** Effective reduction in energy consumption can be achieved through proper energy auditing of the seafood industry. Energy audits can give an idea about the extent of energy utilized for various purposes in the industry and accordingly energy conservation measures can be executed. The energy auditing can be made easy through software like Energy Datamatrix which periodically check the energy consumption in seafood processing sectors.

vi ***Use of renewable energy and green industry concept:*** Switching to renewable energy sources from conventional sources are of great advantage not only to the industry but also to the environment as a whole. Nowadays, the green industry is a trending concept which emphasizes on those activities and measures which help curb environmental depletion, swapping to renewable energy.

3.2 Water Optimization Methodologies

Substantial reduction in water consumption of a seafood processing industry can be brought about by adopting some of the below-mentioned methods.

i ***Automation of equipment and process-line:***The extent of reduction in water consumption possible by automating the equipment cannot be overlooked. Conventional taps may be replaced by self-closing ones. Cut-off valves, flow diversion valves etc. are dependable accessories which may be installed in the process-line to reduce water wastage. Sensor based solenoid valves may be fitted to the water supply system which can be operated automatically or by means of an Internet of Things (IoT) system.

ii ***Monitoring water use pattern:***Close monitoring of the industry's water use pattern can give a lot of insights. Sensors may be installed in relevant points in the process-line for the same. This can be especially helpful in detecting any leaks by observing the sensor readings during the night. Even though this can incur some initial expenses to the industry, the savings both in terms of money and resources are exceptionally high. Many researchers have successfully developed system for online water monitoring based on different algorithms and tools like genetic Algorithm, Artificial neural networks, ZigBee, GPRS etc.(Liu et al, 2013; Yu et al., 2016).

iii ***Recirculation and recycling:*** Considering the safety standards a seafood industry should maintain and there are some constraints in adopting recycling of water in the process line. Nevertheless, opportunities for possible recirculation of water may be explored to reduce water consumption. Recirculated water can be used for employee wash rooms, Effluent Treatment Plant (ETP) operations and direct groundwater recharging. According to the literature, it is anticipated that a recycling unit in thawing equipment can reduce water consumption by 60 %.The different methods used for the treatment of wastewater in seafood industries are dissolved air floatation, dual media filter, activated carbon filter, sand filtration and tank stabilization, flash mixer,

clariflocculator, secondary clarifiers and sludge drying beds, etc. Coarse material and settleable solids are removed during primary treatments by screening, grit removal and sedimentation.

iv ***Updating or modifying conventional systems:***Minor changes may be incorporated into the existing system to utilize the available resources smartly. For example, trigger action shut off devices or nozzles can be fitted onto the hose, the addition of timers or pedals to ensure water, adjusting the flow to the minimum required to maintain performance etc. This can be relative very cheap in investment but can tremendously improve the cleaning potential of water since it is pressurized during application. Almost 40% reduction in water usage can be attained by this method.

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