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Design, development and fabrication of batch type continuous UV-C light system for food products

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Abstract
Foods are generally processed by conventional heat treatment to ensure food free from enzymes and microorganisms. But it can lead to reduction of nutritional quality and sensory properties of the foods products. In order to avoid these undesirable changes during the heat treatment, Non-thermal technologies especially Ultraviolet processing technique plays very important role in processing of food products. This technology has already been approved as alternative treatment to thermal pasteurization of fresh juices, U.S. Food and Drug Administration. This study was aimed to design, development and fabrication of batch type continuous UV-C system for food products. The system was designed such that distance of sample from lamp source can be varied. Two 18 W low pressure mercury vapor UV lamp which emits the UV-C light in the wave length ranges from 200-300 nm were mounted at the top of treatment chamber. Manually operated switches were used to control the treatment time. A mark which has dimensions of a standard Petri dish was placed on the holder platform. The platform that is able to move upward or downward to maintain the various sample distances (viz. 10, 20, 30 and 40 cm) from lamp source by using a tray system. The complete system is fabricated with ply-wood, Decola and aluminum sheets is used for proper finishing of the chamber. The total cost of equipment was calculated to be Rs. 5390/-.

Keywords: Mosambi juice, Ultraviolet treatment, Thermal treatment, pH, TSS

Introduction
Food safety is one of the most important issues that food industries and food service companies have to face. Currently, the heat treatment is still the most common, available and best understood method of inactivation of microorganisms and enzymes, thereby prolonging the shelf life of food. However, heat processing may cause significant changes in the quality and organoleptic characteristics of food. The increasing interest of the consumers for fresh-like, minimal processed food products and the negative attitude to the addition of preservatives chemically synthesized in food has led to the development of alternative methods of processing. Non-thermal processing methods include high hydrostatic pressure or high pressure processing (HPP) (Oey *et al*, 2008) pulsed electric fields (PEF) (Evrendilek *et al*, 2000), ultrasound technology (Rastogi *et al*, 2011), ultraviolet (UV) light treatment (Bintsis *et al*, 2010) and combinations of these (Noci *et al*, 2008) are gaining popular because of the retention of nutritional properties. However, the ultraviolet treatment is better among other non-thermal processing methods in terms of cost and efficiency to inactivate food borne pathogens. The use of UV light for water sterilization and wastewater disinfection, air treatment and decontamination of surfaces and packaging in the food industry (McDonald *et al*, 200) has been well known for decades and is continuously developed.

UV light occupies a small band of electromagnetic radiation found in nature. It is situated between visible light and X-rays, having wavelengths between 10 nm and 400 nm. UV light spectrum has frequencies invisible to humans and visible to some birds and insects. According to ISO 21348-2007, standard on determining solar irradiances, the range of UV wavelengths used in experiments is situated between 200 and 400 nm and is divided in three parts: UV-A, UV-B and UV-C.

UV-A (315–400 nm) contains long UV waves and is normally responsible for changes in human skin called tanning. UV-B (280–315 nm) contains medium UV waves. A smaller fraction of this region (295–297 nm) is responsible for the formation of vitamin D in all organisms that make this vitamin, including humans. UV-B light is attenuated in a similar way as UV-C light, being absorbed by the ozone layer in proportion of around 97%. A small part of UV-B light reaches the surface of the Earth and would cause much damage to living organisms such as skin burns and possibly lead to skin cancer.

Finally, UV-C (200–280 nm) found in sunlight is completely absorbed in the upper and middle parts of atmosphere by ozone and molecular oxygen. It contains short UV waves and is called the germicidal domain because it effectively inactivates microorganisms (Koutchma *et al*, 2009).

By considering all these factors, this study was aimed to design, development and fabrication of continuous ultraviolet chamber for liquid food products.

Materials and method

Materials Used for Fabrication of Continuous UV-C system

UV-C light

Two 18 W low pressure mercury vapor UV lamps which emits the UV-C light in the wave length ranges from 200-300 nm were purchased from market (Fig 3.1). The two lights were placed at top side of the chamber.

Fig 1: Mercury UV-C lamps

Ply-wood

One 8×4 feet ply-wood with thickness of 18 mm is used for fabrication of UV-C chamber. The Ply-wood is cut into 6 pieces of various sizes (Two pieces of 90×40 cm, two pieces of 90×60 cm and two pieces of 60×40 cm). After cutting into pieces, the Ply-wood is planned to make smooth surface.

Fig 2: Ply-wood

Aluminum sheet

0.6 mm thick aluminum sheet is used to cover interior part of the chamber for good reflection of UV photons. The sheet was cut into various pieces of same size of the Ply-wood pieces.

Fig 3: Aluminum sheet

Beadings

Beadings were used to tighten and fix the aluminum sheet properly inside the chamber. The beadings used are flat beading, corner beading and round beading.

L-bars

The L-bars are used for holding the platform inside the chamber. A total of 3 racks were placed inside the chamber with 10 cm distance between each rack and also a distance of 10 cm from top rack to UV light.

Aluminum screws

A ¾" size of aluminum screws with half threaded and full threaded were used for fixing of L-bars.

Decola

A Decola with 8×4 feet sizes with thickness 0.8 mm is used for the smoothening of chamber from outside.

Decola cutter

A Decola cutter is a type of knife which is specially designed for the purpose of cutting decola into required sizes.

Fevicol and tape

These are used for proper pasting or sticking of decola with ply-wood.

Nails

Nails are used for fixing of two cut pieces firmly. ½" size nails were used in fixing of chamber tightly.

Hinges

It is used for joining of door piece to the chamber.

Handles

Handle is used to provide a proper grip for holding and lifting of door easily

Legs

Four rubber legs having height 2" is used to hold the entire set up above the ground level.

Lock hooks

Lock hooks are used for closing the chamber.

SS screws

SS screws are used for fitting the hinges and legs which require more strength to hold them.

Design of UV-C Irradiation Chamber

Continuous UV light apparatus (Fig 4) was developed at College of Agricultural Engineering, Kandi, Sangareddy during this study. The system was designed such that distance of sample from lamp source can be varied. Two 18 W low pressure mercury vapor UV lamp which emits the UV-C light in the wave length ranges from 200-300 nm were mounted at the top of treatment chamber. Manually operated switches were used to control the treatment time. A mark which has dimensions of a standard Petri dish was placed on the holder platform. The platform that is able to move upward or downward to maintain the various sample distances (viz. 10, 20, 30 and 40 cm) from lamp source by using a tray system. In order to prevent the direct contact of UV light to human skin a cover was closed in front of the system. The complete system is fabricated with ply-wood, Decola and aluminum sheets is used for proper finishing of the chamber. Before the treatment lamps were switched on about 30 minutes to provide complete activation and the incident light intensity was determined by using approximation by Bolton's formula(Bolton, 1999), formula (1) in combination with Beer-Lamberts formula, formula (2). AUV sensor which is specific for 254 nm wavelength will also be used to measure the light intensity at the surface of the sample for future studies. The sensor will be placed below the light source on to the shaker in order to provide the same distance with the sample. The measurements were calculated in mW/cm^2 unit.

$$E(x,H) = \frac{\theta}{4\pi L x}\left(arctan\left(\frac{\frac{L}{2}+H}{x}\right) + arctan\left(\frac{\frac{L}{2}-H}{x}\right)\right) \quad \text{..... (1)}$$

Where
E (x,H) is the Fluence rate measured in mW/cm^2 at (x,H)
H is the center to center distance from lamp to petri dish.
L is length of the UV light source
x is the radius of the petri dish
θ is the Source radiant power in Watts
Samples were subjected to different UV dose values. UV dose is the product of exposure time (t = minute) and average UV intensity value (Iavg = mW/cm^2). Average fluence rate was calculated according to an integration of Beer-Lambert Law

$$Iavg = I0 * (1 - \exp(-Ae * L)) / Ae * L \quad \text{............ (2)}$$

In this equation, I_0 represents the incident light intensity (mW/cm^2), Ae value indicates the absorption coefficient (1/cm) and L is the path length (cm).
The setup is represented in the following figures. The figure (4) and (5) represent the front view, side view, top view and 3-D view of the setup respectively.

Fabrication of UV Chamber

A low cost UV-C chamber was fabricated with dimensions of 90×40×60 cm (L×W×H) with a thickness of 18mm using ply-wood. Firstly a 240×120 cm ply-wood was taken and cut into 6 pieces of different sizes.

1. Two pieces of 90×40 cm (top and bottom)
2. Two pieces of 60×40 cm (sides of the chamber)
3. Two pieces of 90×60 cm (front and back of the chamber).

Plaining is performed on sides of plywood on planning machine to maintain uniformity on all sides. All the cut pieces of plywood are joined firmly together with the help of 1½" inch nails. The front piece is cut into two pieces 90×45 cm (bottom) and 90×15cm (top). This is done in order to avoid direct contact with UV light, and the two cut pieces are joined together with help of hinges to make a door
The inner side of the chamber is coated with an aluminum sheet on all the six sides such that no light can escape from the chamber and for better reflection of UV light. The thickness of aluminum sheet is 0.6 mm which can be easily bent and makes easier in fabricating.
Three platforms are made which are detachable and can be placed with a spacing of 10 cm between each and two UV-C lights of 18W each are having wavelength range between 200-300 nm was mounted at the top which is connected to a switch which was mounted to the side wall of the setup. This in turn was connected to the power source.

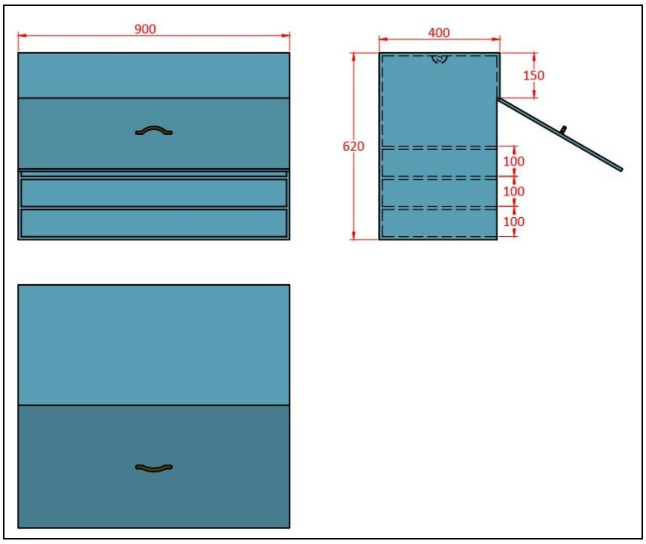

Fig 4: Third angle projection of experimental setup

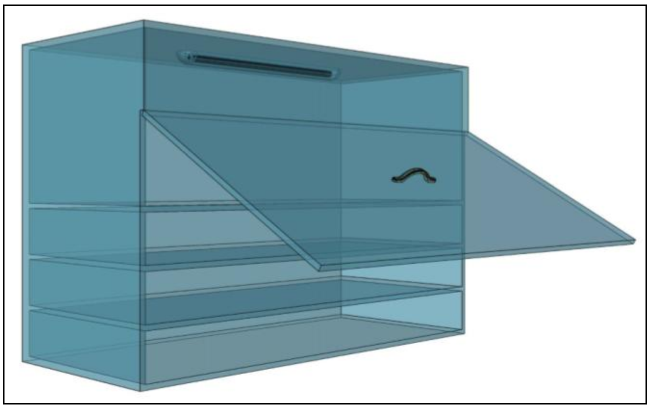

Fig 5: Three dimensional view of UV-C chamber

Cost Estimation of UV-C System

The detailed cost of UV-C chamber was estimated by adding the cost of all the materials / parts /items used for fabrication of system. The total cost of fabrication was expressed in rupees.

Results and discussion

Lab Scale Continuous UV- C system

The lab scale set up was made with plywood and a coating with aluminum sheet and decola was given to the setup. The platform is detachable and can be adjusted such that the distance from the lamp source can be varied. Two 18 Watt low pressure UV lamp (200-300 nm wavelengths) were mounted at the top which is connected to the switches which was mounted to the side wall of the setup. This in turn was connected to the power source. The dimensions of the set up were 90×60×40 cm and the platform can be mounted at variable distances of 10, 20, 30 and 40 cm from the lamp source. The lamp length is 58 cm. The final set up is presented in figure 4.1

Fig 1: Lab scale treatment chamber after fabrication.

Cost Estimation of UV-C System

The detailed cost estimation is presented in Table 1. The total manufacturing cost of the system was calculated to be Rs. 5390/-

Table 1: Cost estimation of UV-C system

S. No.	Particular	Quantity (No.)	Unit cost (Rs.)	Total cost (Rs.)
1	UV light with holder	2	450	900/-
2	18 mm plywood	1	1760	1760/-
3	Decola	1	550	550/-
4	Aluminum Sheet	1	750	750/-
5	Switch board and Miscellaneous items	-	-	1430/-
Total				5390/-

Conclusions

Design, development and fabrication of UV-C system was carried out during this study. The chamber was designed such a way that, the liquid sample can be treated at various distance of sample from lamp source. The total cost of the system was calculated to be Rs. 5390/- only.

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