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INVESTIGATION INTO SUITABLE MATERIAL FOR CONSTRUCTION OF RAW MILK PASTEURIZER

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Abstract

Heat exchanger- versatile equipment which finds its application in both industrial and domestic environment was designed with the principle of recycled heat transfer technique over a short concentric tube heat exchanger. The aim was to ascertain its viability to select the suitable material for the heat exchanger and components fabrication. A host of common pipe materials were selected and passed through heat transfer test to obtain coefficient of heat transfer of each material and also Biochemical analysis to validate selection of the better material. The thermal conductivity of each material is the instrument for obtaining each heat transfer coefficient with stainless steel having the most suitable and safest at $U_{i(0.1)} = 1.355$, $U_{i(0.15)} = 2.032$, $U_{i(0.2)} = 3.386$, $U_{i(0.25)} = 3.519$ and $U_{i(0.3)} = 3.661$. Also, the three critical parameters for biochemical analysis which were considered provided stainless steel with the better values of mean velocity and standard deviation for safety of milk consumption standing at 24.30 ± 0.01, 2.81 ± 0.01 and 6.65 ± 0.01 for Titratable acidity, Casein level and PH level respectively. These results ensure safe milk consumption.

Keywords: short concentric tube heat exchanger, long temperature and cycle pasteurization
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1.0 INTRODUCTION

Heat transfer applications in both industrial and residual processes have affected the quality of eaten food, living and life style. As such, understanding and control of heat flow through the right heat exchanger materials, thermal insulation and other supporting devices are used continuously to solve basic or fundamental human problems (Greiner, 2000). Thermal processing is the ultimate "safe harbor" for milk safety, it should be clear that it is one of those technologies where critical understanding and appropriate application of heat transfer material requirement in the thermal processing design should not be overlooked (Holdsworth, 1985). Heat transfer coefficient is a property of a situation that reflects the relation of a particular surface with the fluid and how they are in contact. It is a measure of the rate at which heat is transferred from a surface into a bulk fluid. The mechanism for heat transfer from the surface to the fluid is basically by its convection and conduction (dominated by the flow of the fluid, natural or forced) and more importantly by conduction due to the thermal conductivity of the material which is responsible for a kind of heat transfer coefficient of different materials (Bird et al., 2002; Geankoplis, 2003). The thermal conductivity of a material is the physical quantity that measures the rate at which heat moves through the material by conduction. It is a fundamental transport coefficient like viscosity and diffusivity (Bird *et al*., 2002).

Common metals include beryllium, mercury, copper, aluminium, lead, antimony, zinc, etc. According to late Dr. Henry Schroeder, who is an authority on trace element, human body produce enough of what is required of this element such that when in excess becomes toxic. The metals inhibits, over stimulate or otherwise alter thousands of enzymes and the situation contributes to many health conditions (Varsha, Nidhi, Anurag ,Singh and sanjay, 2013). The base polymers are generally considered inert but plastics or PVC packaging contains a variety of low molecular weight compounds (di-2-ethylhexyladipate (DEHA)) that could potentially migrate in the milk with consequences of affecting the quality or substance of the food been altered or class of the food constituents such as flavor or aroma compound affected (Mercer, 1990). According to Green, 2011, polyvinyl chloride (PVC) is a chlorinated plastic made ready for various uses by the addition of filters, stabilizers, lubricants, plasticized, pigments and flame retardants. The two major hazards during its lifecycle use include: its manufacture and incineration produce 'dioxin' and its plasticizer DEHP can leach from PVC products to those using them. The burning of PVC, especially in home fire or hot environment result in the release of "dioxins", the hydro-chloric acid formed when PVC is burned and can lead to life-threatening Lung and liver damage. It also leads to reproductive damage (Leus and Westhuizen, 2003). The Polyflon (PTFE) is composed of polytetrafuluoroethylene from where its acronym is derived. PTFE is superior in heat resistance and chemical resistance compared with the other plastics. Teflon is made up of a chemical known as perfluorooctanoic acid (PFOA), which has been labeled carcinogenic by a scientific review panel that advises the U.S. Environmental Protection Agency (EPA)(Ellis, 2001).At the beginning of the 20th Century, H Brearly, working in Sheffield, England was trying to develop a tougher material for rifles. He found by chance that a steel containing about 0.3% carbon and 13% chromium did not corrode in the laboratory environment and this, stainless was born. Further work showed that the chromium reacted with oxygen and formed a passive layer of Cr_2O_3 on the surface of the metal which protected the steel against corrosive environments. (Outokumpu, 2011). It further has durability, including resistance to corrosion and aging in terms milk processing (Thongyai, 2005). According to Damian and Frank, 2000, stainless steel used for milk processing are 304 which contains 18% chromium and 8% nickel while 316 contains 16% chromium, 10% nickel and 2% molybdenum. The molybdenum is added to help resist corrosion to chlorides.

The main component of heat exchanger in raw milk micro-scale pasteurization includes: Concentric tubes, connection pipes and valves, containers, control panel, Boiling ring, pumps and Sensors. What is the right type of heat transfer and safety material required for fabrication of the milk processing heat exchanger and its components?

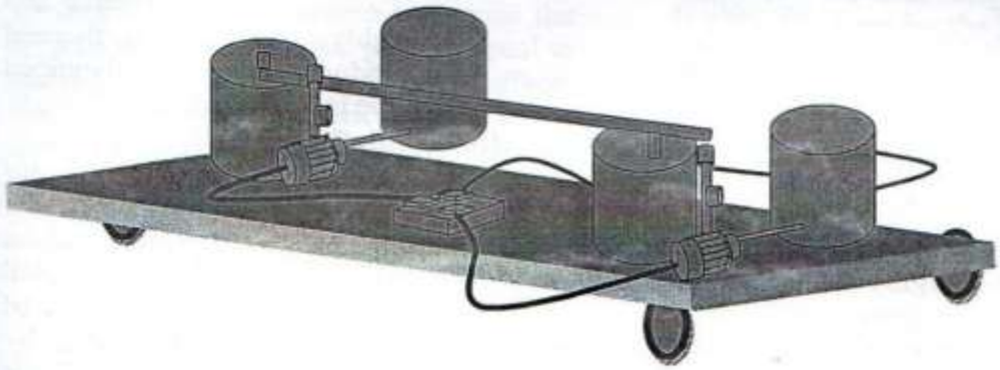

Figure 1: Isometric View of the Heat Exchanger

2.0 The selected Sample Materials and Basic Engineering Properties include:

i. **Plastic pipe:**
The properties of plastic pipe includes; Creep ability, stress relaxation, recovery, water absorption (hygroscopic), corrosion resistance, environmental stress, and light transmission. The thermal conductivity of plastics is 0.5W/m^{2}k.

ii. **Stainless Steel pipe:**
Stainless Steel combines high strength with hardness, very clean, hygienic and excellent surface appearance properties. It is also a good conductor of heat, high ductile strength, high magnetic permeability, highly resistance to corrosion, not easily oxidized, retain it cutting edge for a long time and remains tough at cryogenic temperatures. The thermal conductivity of stainless steel is 16 W/m^{2}k.

iii. **Aluminum pipe:**
Aluminum has density of 2.7g/cm^3, high melting point of 519°C, resistance to oxidation, very ductile and highly resistance to corrosion. The thermal conductivity of Aluminium is 205 W/m^{2}k.

iv. **Copper pipe:**
Copper is reddish-brown with density of 8.93g/cm^3, high melting point, 1083°C, highly malleable and ductile at ordinary temperatures, it becomes brittle near melting point, and a very good conductor or heat and electricity. The thermal conductivity of Copper is 401W/m^{2}k.

v. **Polyvinyl chloride (PVC) pipe:**

It has weathering stability, versatility, longevity, energy recovery, good hygiene, good barrier properties, recyclability, public safety and economic efficiency. The thermal conductivity of PVC is 0.19 W/m^{2}k.

vi. **Iron Pipe:**
Iron has high density of 7.86g/cm^3, high melting point 1539^{o}C, highly malleable and ductile, ferromagnetic, high tensile strength and weak corrosion resistance. The thermal conductivity of iron is 80 W/m^{2}k.

vii. **Galvanized Steel pipe:**
Has high corrosion resistance and good surface appearance. It also has resistance to cracking, loss of adhesion and highly durable. The thermal conductivity of galvanized pipe is 71.8 W/m^{2}k.

viii. **Polyflon (PTFE):**
Polyflon is composed of polytetraflouroethylene. PTFE has a very long chain molecular structure in which all of the hydrogen atoms of polyrthylene are replaced by fluorine atoms. PTFE is superior in heat resistance and chemical resistance compared with the other plastics. The thermal conductivity of iron is 0.25 W/m^{2}k

3.0 Methodology of obtaining overall Heat Transfer Coefficient

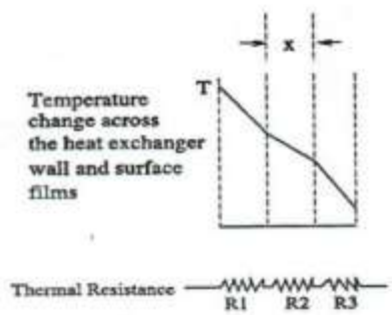

Figure 2: Temperature drop across the heat exchanger plate

Figure 2 shows the flat plate of a heat exchanger with stagnant fluid films formed on both sides. Stationary surface films are formed due to the friction between the metallic surface and the moving fluid. Surface films and metallic wall pose a resistance to heat flow. Resistance of surface films and metallic wall can be considered in series, which allows their addition to obtain the total resistance:

$$R_1 = \frac{1}{h_i A} + \frac{x}{kA} + \frac{1}{h_o A} \qquad 1$$

Where, $\frac{1}{h_iA}$, $\frac{x}{kA}$ and $\frac{1}{h_oA}$ are the resistances posed by the hot film, metallic plate, and cold film, respectively. The same area, A, is used for three resistances because the area on each side of a flat plate is equal to the area of the film covering its surface. For resistances in series, the larger components dominate in determining the total resistance. In heat exchangers, the resistance posed by the metallic wall is usually smaller than that by the film. Therefore, the total resistance to heat flow is affected more by the film properties as compared to the metallic wall.

The overall heat transfer coefficient can be calculated as (Rajput, 2006):

$$U = \frac{1}{AR_t} = \frac{1}{\frac{1}{h_i} + \frac{x}{k} + \frac{1}{h_o}} \qquad 2$$

$$U = \frac{1}{\frac{1}{h_i} + \frac{L}{k} + \frac{1}{h_o}} \qquad 3$$

If the fluids are separated by tube wall, the overall heat transfer coefficient is given by (Rajput, 2006):

$$U_i = \frac{1}{\frac{1}{h_iA_i} + \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi kl} + \frac{1}{h_oA_o}} \qquad 4$$

The experimental procedure is to replace each heat transfer area of concentric tube with a particular type of material before cycles/minutes heat transfer takes place in 8 minutes for each.

$$U_{i_{Aluminium(0.3)}} = \frac{1}{\frac{1}{500\times 2\pi\times 0.00625\times 0.3} + \frac{\ln\left(\frac{0.009375}{0.000625}\right)}{2\pi\times 205\times 0.3} + \frac{1}{900\times 2\pi\times 0.009375\times 0.3}}$$

$$= \frac{1}{0.1698 + \frac{0.4055}{386.415} + 0.06288}$$

$$= \frac{1}{0.1698+0.001049+0.06288} = \frac{1}{0.2337}$$

$$= 4.278$$

$U_{i_{Galvanized\ Iron\ pipe(0.3)}} = 4.243$

$U_{i_{Copper(0.3)}} = 4.288$ $U_{i_{Plastic(0.3)}} = 1.509$ $U_{i_{Iron(0.3)}} = 4.249$

$U_{i_{PTFE(0.3)}} = 4.249$ $U_{i_{PVC(0.3)}} = 0.733$

$$U_{i_{Stainless\ Steel(0.3)}} = \frac{1}{\frac{1}{500\times2\pi\times0.00625\times0.3}+\frac{\ln\left(\frac{0.009375}{0.000625}\right)}{2\pi\times16\times0.3}+\frac{1}{900\times2\pi\times0.009375\times0.3}}$$

$$= \frac{1}{0.1698 + 0.013445 + 0.06288}$$

$$= 3.661$$

4.0 Methodology of Biochemical Analysis

In order to select a good material for use in heat treatment of milk a host of common materials where pass through Biochemical Analysis with consideration to three very important parameters which includes titrable acidity, casein level and pH level in relation to each materials. The essence is to check high acidity content of the milk, allergy or reaction of the milk consumption and the pH which has to be within required level for appropriate taste and flavor in relation to the material used respectively.

4.1 Determination of Titratable Acidity of Unpasteurized Milk in Relation to the Materials

20mls of unpasteurized milk sample was measured into a conical flask to which five drops of phenolphthalein was added and properly mixed. 0.1M NaOH was poured into a clamped burette and titrated against the unpasteurized milk sample until a permanent pink phenolphthalein end-point was obtained. The acidity in g/100mls of unpasteurized milk sample was determined using the formula:

$$\frac{C_A V_A}{C_A V_A} = \frac{N_A}{N_B}$$

4.2 Determination of Casein Level of Unpasteurized milk in relation to the sample materials

100mls of unpasteurized milk sample was divided and placed in four centrifuge tubes (25 ml each). The milk was then centrifuged 4,000 rpm for 20 minutes. After centrifugation, the fats and lipids was carefully removed from the surface. The milk was transferred into a beaker and mixed with equal volume of distilled water. 0.1N HCl was added to the mixture and stirred until a curdy precipitate was formed. The mixture was then filtered using a filter paper to collect the precipitate. The precipitate (residue) was then washed with distilled water to remove salts and then with diethyl ether to remove any fat or lipid left and finally ethanol. The precipitate was dried and the weight taken as weight of casein in percentage.

4.3 Determination of pH of unpasteurized milk in relation to the Sample Materials.

The pH meter was switch on and was adjusted using the buffer control knob to pH 7.0 The electrode was rinsed with distilled water and wiped to remove excess. After the electrode was rinsed it was placed in a standard buffer of known pH 4.0 and the meter adjusted for correct reading. The electrode was then re-rinsed in distilled water as before, then placed in the solution to be measured and the reading was taken. It was also ensured that the electrode bulbs are immersed in the solution. The electrode was rinsed again in distilled water and place in buffer, pH 7.0. The pH meter was then switched to "standby"

5.0 Results and Discussion

Table 1 below shows results of coefficient of heat transfer for Plastic, Aluminium, Stainless steel, copper, iron, galvanized, Polyvinyl chloride and PTFE pipes treated with pasteurized milk. The table shows values of Time, Length and coefficient of heat transfer in each case of experiments carried out. The values of result for each material are then plotted against time to provide the necessary understanding of analysis and study as shown in figure 3.

Table 1: Coefficient of heat transfer of selected materials

Time (min)	Length (m)	Aluminium W/m^2k	Galvanized Ironl W/m^2k	Copper W/m^2k	Iron W/m^2k	Plastics W/m^2k	PTFE W/m^2k	PVC W/m^2k	Stainless steel W/m^2k
1.6	0.1	1.426	1.420	1.429	1.417	0.503	0.305	0.244	1.355
3.2	0.15	2.139	2.122	2.116	2.125	0.754	0.482	0.366	2.032
4.8	0.2	3.565	3.537	3.573	3.541	1.099	0.643	0.509	3.386
6.4	0.25	3.765	3.725	3.776	3.731	1.257	0.762	0.611	3.519
8	0.3	4.223	4.243	4.288	4.249	1.509	1.093	0.733	3.661

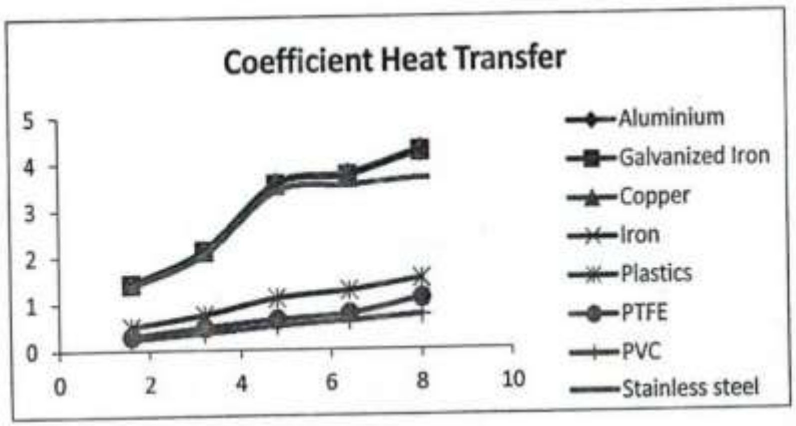

Figure 3: Plot indicating Heat transfer Coefficient of each material

The heat transfer coefficient parameter is the proportionality coefficient between the heat flux and it driving forces as heat is been transferred between service media and the product. It is essential that a material is selected with respect to heat transfer coefficient in such away as not to destroy the nutritive value or keep the nutritive values of milk intact for consumption. As depicted in figure 3 above, the coefficient of heat transfer of Stainless steel representing both of water and milk side shows that at hydrodynamic entrance region, the milk gain heat so that it's density and viscosity is reduced for efficient heat transfer, these coefficient of heat transfer increases rapidly up to a time that the viscosity and density is heavily stretched. The coefficient of heat transfer is then reduced through the remaining number of cycles/minute of the experiment to keep the milk's nutritive values safe for consumption. Again, from the same figure, Aluminium, copper, iron and galvanized iron pipes exhibited the same behavior but the coefficient of heat transfer rises towards the tail end of number of cycles/minutes which is capable of destroying the nutritive values of the milk because the viscosity and density is already stretched thereby making it unsuitable for consumption. Also, Plastic, Polyvinylchloride and PTFE pipes have very low coefficient of heat transfer which is incapable of providing the pasteurization temperature of the milk or 63^0C pastuerization temperature level of milk so desired.

The results for both the titrable acidity, pH and casein value of the unpasteurized milk sample as treated with Plastic, Aluminium, Stainless steel, copper, iron, galvanized, Polyvinyl chloride and chlorinated polyvinyl chloride pipes for 2 hours are tabulated below in table 2. The table shows result of three samples (AB & C) of each material for titrable acidity and pH levels experiment carried out. The mean value of the results is then taken and the standard deviation provided for reference. The mean values of result for each material are them plotted for the case of titrable acidity, casein and pH of experiment to provide the necessary understanding of analysis and study.

Table 2: Biochemical analysis of sample materials

S/N	Sample type (Treatment)	Titratable acidity (gram lactic acid/100mls)				Casein (%)				pH			
		A	B	C	Mean ± SD	A	B	C	Mean ± SD	A	B	C	Mean ± SD
1.	Plastic pipe	25.25	25.30	25.20	25.20 ± 0.05	2.82	2.83	2.81	2.82 ± 0.01	6.12	6.13	6.11	6.12 ± 0.01
2.	Aluminium pipe	26.45	26.55	26.50	26.55 ± 0.5	4.26	4.28	4.27	4.28 ± 0.01	6.23	6.22	6.21	6.21 ± 0.01
3.	Stainless steel pipe	24.29	24.30	24.31	24.30 ± 0.01	2.81	2.82	2.80	2.81 ± 0.01	6.51	6.71	6.72	6.65 ± 0.01
4.	Copper pipe	26.50	26.45	26.55	26.55 ± 0.5	3.45	3.47	3.46	3.46 ± 0.01	6.61	6.60	6.62	6.61 ± 0.01
5.	Iron pipe	36.30	36.25	36.00	36.00 ± 0.05	3.83	3.86	3.80	3.83 ± 0.03	6.21	6.23	6.22	6.21 ± 0.01
6.	Galvanized pipe	27.10	27.00	27.20	27.00 ±0.1	3.90	3.94	3.92	3.92 ± 0.02	6.41	6.42	6.43	6.41 ± 0.01
7.	Polyvinyl chloride pipe	27.10	27.00	27.20	27.00 ± 0.1	3.16	3.20	3.18	3.18 ± 0.02	6.88	6.79	6.80	6.81 ± 0.01
8.	Polyflon (PTFE)	25.90	26.10	26.20	25.90 ± 0.01	2.62	2.60	2.63	2.62 ± 0.01	6.11	6.13	6.12	6.11 ± 0.01

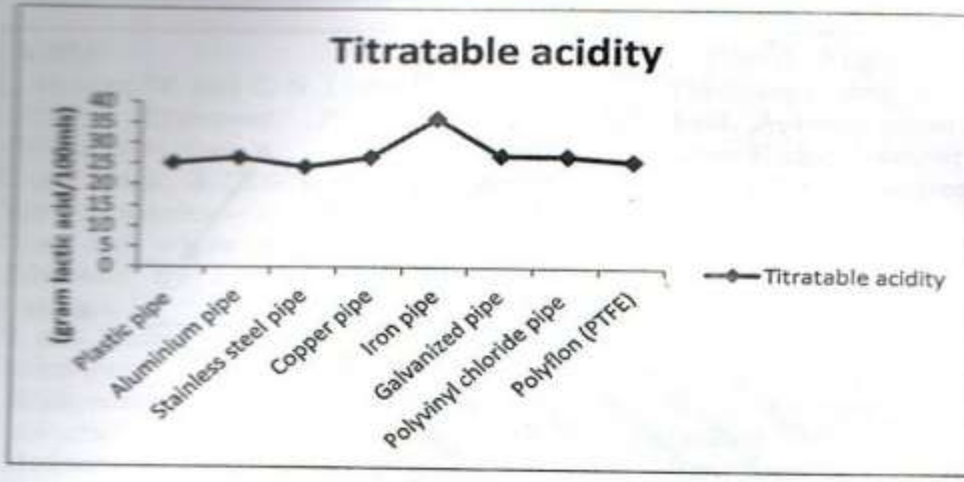

Figure 4: Titratable acidity of sample materials

Generally, titrable acidity means the total acidity (natural and developed) or titrable acidity which was determine by titrating a volume of milk with standard alkali to the point of an indicator line phenolphthalein turning from colourless to pink. It is actually the lactic acidity produced by milk or developed by citrate and phosphates present in the milk. It is necessary for it to be as low as possible in content and stainless steel provided the lowest titrable acidity of the analysis as shown in figure 4 above with a mean value of 24.30.

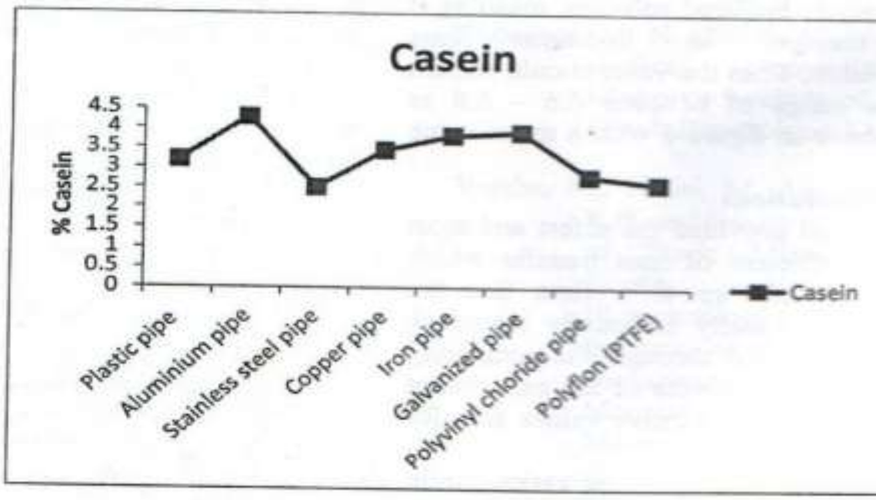

Figure 5: % Casein of sample materials

The casein is a class of protein in the milk which when it is too high causes allergies or reaction. Sometimes these allergies are swollen lips, month, lung or skin reaction or nasal congestion. In this case the body's immune system mistakenly thinks protein is harmful and inappropriately produces allergic antibodies for protection. In the experimental biochemical analysis, stainless steel gave the lowest level of casein as shown in figure 5 above with a mean value of 2.81.

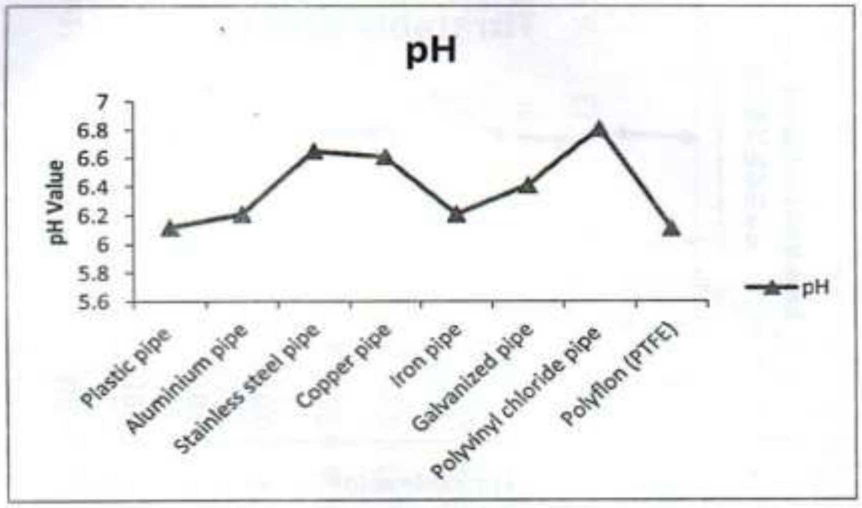

Figure 6: pH of sample materials

A very low pH indicates heavy bacterial action and milk spoilage. The pH number of a solution is inversely proportional to the concentration of hydrogen ions present. Acid release hydrogen ions and have as lower pH. The milk proteins and salts allow milk to act as buffered solution, meaning it resist changes in hydrogen ions concentration. Thus the value should remain a narrow range of between 6.6 – 6.8 as shown above in figure 6 with a mean value of 6.65.

6.0 Conclusions

Stainless steel provided the safest and most suitable coefficient of heat transfer which increases rapidly up to a time that the viscosity and density is heavily stretched, and then reduced through the remaining number of cycles/minute of the experiment to keep the milk's nutritive values safe for consumption.

From figures 4, 5 and 6, the various milk treatments showed varying titratable acidities which is much higher than established value for Iron pipe, plastic pipe, PTFE and PVC pipe treatments while stainless steel pipe treatment showed the lowest titratable acidity. For casein, aluminium, copper, iron, galvanized pipe, PTFE pipe and PVC pipe treatment all showed values higher than pure milk sample for casein in milk (i.e. 2 – 3.8%). Stainless steel pipe shows values of caseins which agreed with the established values of casein in pure milk sample. For pH, Stainless steel PH is within limit while copper, aluminium, PTFE and plastics and PVC pipes have the off pH values in relation to the milk. The pH of milk is expected to be 6.6-6.8 before and after pasteurization.

7.0 Recommendation

From the combination of results discussed above stainless steel has a very good material property for milk processing due to its suitability and safest coefficient of heat transfer. Also, its lowest % titratable acidity, % casein level and pH within required limit makes it more safe material for milk consumption. It is recommended that stainless steel pipes be materials choice for milk processing and consumption safety.

REFERENCIES

Bird, R. B., Stewart, W. and E. N. Lightfoot (2002). *Transport Processes* (Wiley: New York,).

Damian, K and Frank, A (2003). Stainless Steel Properties – How to Weld them and where to use them. Published by Liconln Electric Company.

David L. N. and Michael M. (2014). Cox *Lehninger Principles of Biochemistry* Fourth edition (university of Wisconsin–Madison)- **www.whfreeman.com/lehninger 4e. Retrieved On** 29th September, 2014.

Ellis, D.A. Mabury, S.A., Marten, J.W. and Muir D.C.G. (2001). Thermolysis of fluoropolymers as a potential source of halogenated organic acids in the environment" Nature 412(6844):321 – 324.

Geankoplis, C. (2003). *Transport Processes and Separation Process Principles* (Prentice Hall: Englewood Cliffs, NJ).

Greiner, H. and Bussick, F (2000) "*Mechanical Sealing for Heat Transfer Fluids*". Lubrication Engineering 56(8), pp 17 – 24.

Green, B. (2001). Healthcare without harm, American College of Nurse Midwives.

Holdsworth, S. D. (1985). Optimination of Thermal Processing – A Review. Camp den Food Preservation Gloucestershire GL556LD, UK – *Journal of Food Engineering 4 (1985)89 – 116.*

Leus JFR, Venter P, and Westhuizen HV. (2003). Enumeration of Potential Microbiological Hazards in Milk from Marginal Urban Settlements in Central, *Africa Journal of Food Microbiology*; 321 – 326.

Mercer A. (1990). Migration Studies of Plasticizers from PVC film into food. A thesis submitted to the Council for National Academic Award for the Degree of Doctor of Philosophy pp3

Outokumpu, S (2011). Materials Selection for Stainless Steels. Presented by Metal Forming Magazine Webinar .

Paul M. A. (2009), Physical properties of milk, Division of Livestock Product technology Faculty of Veterinary Science and Animal husbandry, Austeng, Gandeibal, Kashmir, J. & K, India.

Rajput, R. K. (2006). *Heat and Mass Transfer in SI units*, Third Reviewed Edition, Printed in India by Rajendra Printers (PVt) LTD and Published by S, Chord and Company Ltd, New Delhi pp 563 – 658.

Thongyai, M. N. (2005). Study of stainless surface cleanability: King Mongnt's Institute of Technology Worth Bangkok pp 1 - 6.

Varsha, M., Nidhi, M, Anurag, M, Singh, R.B. and Sanjay M. (2013). Effect of Toxic Metals on Human Health. Department of Biotechnology and Microbiology, Institute of Foreign Trade and Management, Delhi Road, Maradabad, India, Department of Mechanical Engineering, College of Engineering Technology, Maradabad India. Halberg Hospital and Research, Center, Civil Lines, Maradabad, Up India. Department of Biotechnology College of Engineering and Technology, IFTM Campus, Maradabad, Up India. *The Open Nutraceaticals Journal*, Vol. 3:94 – 99.