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Effect of the chemical composition of fluid foods on the rate of fouling processing during sterilization

Efecto de la composición química de los alimentos líquidos sobre la tasa de procesamiento de la suciedad durante la esterilización

Budianto[1], Zefki Okta Feri[2], Anik Suparmi[3], Muh Jaenal Arifin[4]

ABSTRACT

Background: This research was motivated by the determination of the sanitation schedule in the heat exchanger area for some products (milk, avocado juice, and orange juice), as well as the inconsistency of the results of previous studies related to the chemical composition of the fouling layer. **Objectives:** a) to test the effect of raw material composition on the chemical composition of the fouling layer. b) to test microbial growth's effect on fouling's chemical composition (protein). **Methods:** mathematical derivation of the formation process of Resistant Dirt Factor (Rd) in the form of an Equation; ANOVA was used to test the effect of the dependent variable (protein) and predictor (microbial). **Results:** a) The composition of the raw material strongly influences the chemical composition of the fouling layer; b) There is a strong effect between microbial growth and protein content as a fouling composition ($p<0.05$). **Conclusion:** A strong influence between microbial growth and the composition of the fouling layer (protein) can close the research gap related to the inconsistency of previous research results (fouling layer composition), so there is no prolonged debate.

Keywords: Fouling, Resistant Dirt Factor (Rd), Heat Exchanger, Heat transfer (Q), Dairy products

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University of Antioquia
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Filliations
[1]Institute Science and Technology Al-Kamal, Jakarta, Indonesia
[2]Universitas Negeri Yogyakarta, Yogyakarta, Indonesia
[3]SMA Negeri 3 Tarakan, kota Tarakan
[4]SMK Negeri 3 Madiun, Madiun City, East Java, Indonesia

Corresponding
Budianto
budianto_delta@yahoo.com

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RESUMEN

Antecedentes: Esta investigación fue motivada por la determinación del cronograma de sanitización en el área del intercambiador de calor para diferentes productos (leche, jugo de aguacate y jugo de naranja), así como la inconsistencia de los resultados de estudios previos relacionados con la composición química de la capa de suciedad. **Objetivos:** a) probar el efecto de la composición de la materia prima sobre la composición química de la capa de suciedad. b) probar el efecto del crecimiento microbiano en la composición química de la capa de suciedad (proteína). **Método:** etapas del proceso de formación del Factor de Suciedad Resistente (Rd) en forma de una ecuación; Se usó ANOVA para probar el efecto de la variable dependiente (proteína) y el predictor (microbiano). **Resultados:** a) La composición química de la capa de incrustación está fuertemente influenciada por la composición de la materia prima; b) Existe un fuerte efecto entre el crecimiento microbiano sobre el contenido de proteína como composición de ensuciamiento ($p<0.05$). **Conclusión:** Una fuerte influencia entre el crecimiento microbiano y la composición de la capa de incrustación (proteína) puede cerrar la brecha de investigación relacionada con la inconsistencia de los resultados de investigaciones anteriores (composición de la capa de incrustación) para que no haya un debate prolongado.

Palabra clave: Ensuciamiento, Factor de suciedad resistente (Rd), Intercambiador de calor, Transferencia de calor (Q), Productos lácteos

INTRODUCTION

Sterilization is an important process in beverage products. This process has a significant role in maintaining the quality of beverage products. The sterilization area involving the heat exchanger must be protected from dirt because it causes a decrease in heat transfer during sterilization. It takes extra effort to control dirt in the Heat Exchanger (HE) area. The high cost of sterilization control is the main focus of this research. Medium-scale beverage companies in Indonesia still rely on the same process and installation for their products. Therefore, the sanitation schedule in the HE area becomes an obstacle because of differences in composition that affect the rate of dirt formation. This research is empirical by comparing milk drinks, avocado juice, and orange juice to the Resistant Dirt Factor (Rd), the composition of impurities, and the number of contaminant microorganisms. This study also finds out the effect of microbial growth on protein content as an impurity composition.

Previous studies have discussed Rd in the HE area of processing beverage products, especially milk. All the researchers agree that Rd is affected by heat transfer (Q), overall heat transfer coefficient when clean (Uc), and overall heat transfer coefficient after the operation (Ud). Not yet a well-established concept related to (i) which component settles first; (ii) the composition of the impurity layer; (iii) the emergence of microorganisms in the fouling layer; (iv) how protein affects the number of microorganisms in the fouling layer. The long debate until now has caused research to only focus on solutions to problems that occur.

Likewise, this study focuses on solutions by making comparisons: (a) the rate of formation of Rd to determine the sanitation time in the HE area, (b) the composition of the impurity layer, and (c) the effect of the number of microorganisms in the fouling layer on protein. Efforts to fill the research gap can be seen in b and c.

The components of the raw material strongly influence the composition of the fouling layer. One example is dairy drinks. In the sterilization process in HE at a temperature >100 °C, different results were found, namely: (i) protein content was greater than mineral content and fat content was found to be the least (protein > mineral > fat) [1–6] and (ii) Mineral> protein> fat [7, 8]. In the sterilization process in HE at a temperature of 100-140°C also found different results, namely: (i) protein > mineral > fat [4, 9–11] and (ii) Mineral> protein> fat [9, 12, 13]. Research conducted by Skudder [9] gave different results with the same treatment. To prove that Rd is affected by the components of raw materials, this study wants to prove it with samples of drinks from different ingredients, namely milk, avocado juice, and orange juice.

The fouling layer is formed from the components of raw materials [10,11,14–17] and the activity of microorganisms [17–20] due to the ineffectiveness of sterilization in HE. These two topics still dominate the research. There has been no research on the effect of the number of microorganisms on the protein content in the fouling layer. This study wanted to see how decreasing protein levels affect the number of microorganisms in the HE area.

This research is empirical because the data was gathered from beverage companies with variants of milk products, avocado juice, and orange juice. Comparing the three different components can help in understanding whether the composition of the raw material affects: (a) the rate of formation of Rd,

(b) the composition of the fouling layer, and (c) the growth of microorganisms. There is not much information regarding the Rd process for avocado juice and orange juice, so that this study can provide information regarding the two samples.

MATERIAL AND METHOD

The raw materials used in this study were pure milk drinks, avocado juice, and orange juice. The viscosity of the three samples was established at the same level (1.75cP). The chemical composition of the three samples was analyzed for fat, protein, and mineral content based on standard BPOM RI analysis procedures [21].

Table 1. Samples and chemical composition

No	Sample	Nutrition		
		Fat (w/w %)	Protein (w/w%)	Mineral (w/w%)
1	Milk	2.17	3.7	3.01
2	Avocado Juice	2.08	0.98	8.08
3	Orange Juice	0.16	0.24	15.23

This research was conducted in a beverage company, in Jakarta (Indonesia). The tools used for processing are shown in table 2.

Table 2. The parameters of the tool and the Heat Exchanger are in the sterilization process

No	Sensor	Description	Tool Design			
1	TT-44	Sensor inlet temperature of the product	Inner Pipe		Anullus	
2	TT-42	Temperature sensor exit product	Pipe Inner Diameter	0.115 ft	Pipe Inner Diameter	0,1725 ft
3	TT-08	Hot water inlet temperature sensor	Pipe Thickness	0,0256 ft	Pipe Thickness	0,0354 ft
4	TT-09	Temperature sensor comes out of hot water	Flow Area	0,864 $inch^2$	Flow Area	0,986 $inch^2$
5	TT-44	Steam inlet pressure on the PHE	Fluid Type	Milk, juice	Fluid Type	hot water
Heat exchanger double pipe (GLAQ421)			**Type**		**80% efficiency**	**95% efficiency**
			Shell & Tube		Rd: 0.070-0.078 Hr.Ft2.F/Btu	Rd: 0.027-0.035 Hr.Ft2.F/Btu

Working Procedures

a. The three samples received the same treatment, namely the incoming feed around 8,000 L/h. The flow chart is shown in figure 1.

b. Sample observations were carried out in 5 batches (Each processing batch is completed in 110 minutes). Observations included the rate of formation of Rd (see table 3), the number of microorganisms, the composition of the fouling layer in each batch, and the effect of protein content on the growth of microorganisms in the HE pipeline (can be removed to facilitate analysis).

c. Microorganism growth analysis (triple analysis) per 10 minutes was taken from samples that had passed HE [17]. Quantitative microorganism tests included Total Plate Count (TPC), yeast & mold. The procedure for determining TPC, yeast, & mold refers to BPOM RI [21].

d. Meanwhile, samples were taken in the HE pipeline to test the effect of protein content on microbial growth, which was intentionally removed for microbial observation in the fouling layer after the process was completed.

e. Quantitative analysis of microorganism growth tests microbial growth's effect on protein content. A qualitative bacterial test aims to see the type of bacteria in the fouling layer. In both analyses, samples were taken in the HE pipeline (HE pipe was intentionally removed) to observe microbes in the fouling layer after the process was completed. Qualitative microorganism test refers to Setyaningsih et al. [27] and chemical analysis using atomic absorption spectroscopy (AAS) which refers to BPOM RI [21].

f. ANOVA test was used to see the effect of microbial growth on protein content

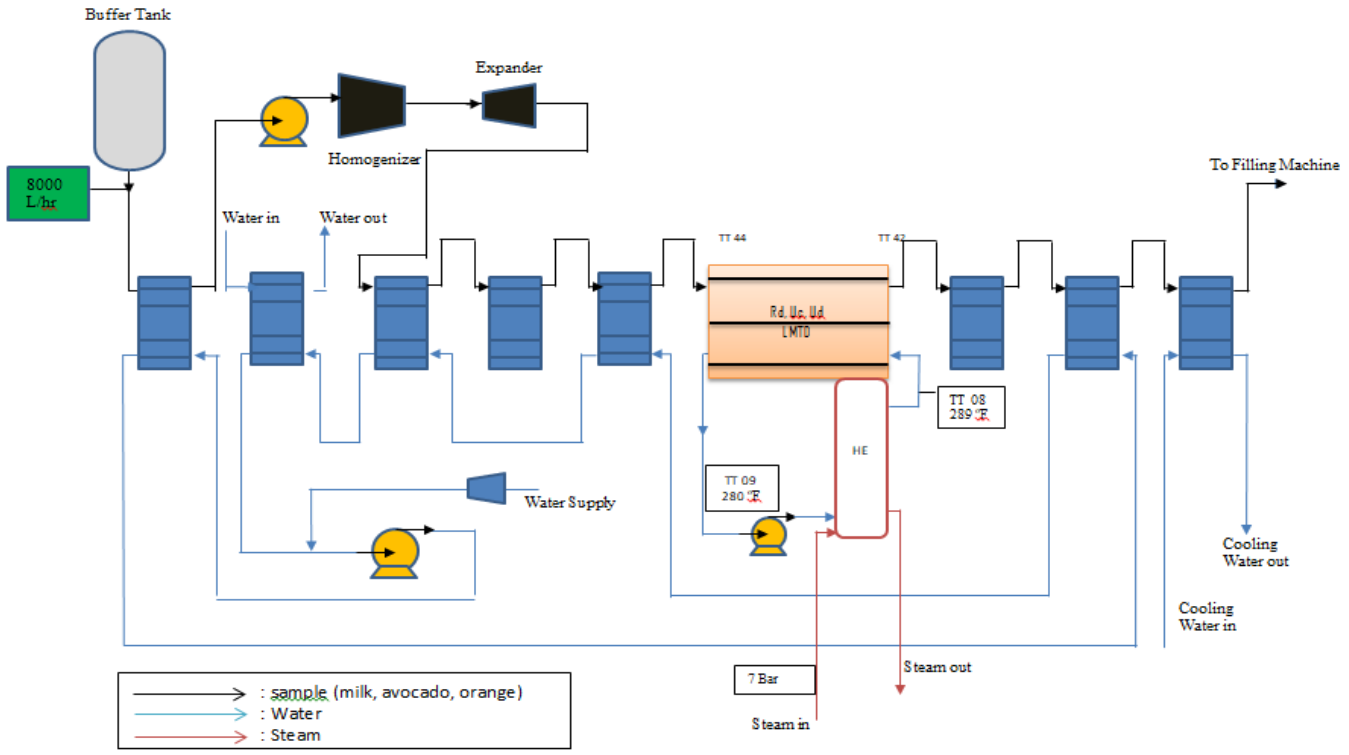


Figure 1. Production process flow chart. The sample goes through a homogenizer, expander, sterilizer (in the HE area), and packing. Test of Resistant Dirt Factor (Rd) in sterilization process.

Table 3 is the stage of the Rd rate calculation process for the three research samples. The stages are sequential from eq. 1 to eq. 13.

Table 3. Equations to predict the value of Resistant Dirt Factor (Rd) [25, 26]

Step	Parameter	Equation	Equation
1	Heat Balance (Q)	Q = W.Cp (T1 - T2)	Eq.1
2	Log mean temperature different (LMTD)	$LMTD = \frac{(T1-t2)-(T2-t1)}{ln((T1-t2)/(T2-t1)}$	Eq.2
3	Temperature calories (Tc)	Tc = T2 + Fc(T1 – T2)	Eq.3
4	Stream Area (α)	$\alpha s = \frac{ID\,x\,C\,x\,B}{144\,x\,PT}$	Eq.4
5	Mass Flow Rate (G)	$G = \frac{w}{a}$	Eq.5
6	Reynold (Re)	$Re = \frac{DexG}{\mu}$	Eq.6
7	Prandtl (Pr)	$Pr = \frac{cpx\,\mu}{k}$	Eq.7
8	Heat Transfer Coefficient ($\frac{h}{\varphi}$)	$\frac{ho}{\varphi} = JH\,x\,\frac{k}{De}x(Pr)^{1/3}$	Eq.8
9	Temperature on the tube wall (tw)	$tw = tc\,x\,\frac{ho/\varphi s}{\frac{hio}{\varphi t}+\frac{ho}{\varphi s}}(Tc-tc)$	Eq.9

Step	Parameter	Equation	Equation
10	Viscosity Ratio (φ)	$\varphi = (\mu / \mu w)^{0,14}$	Eq.10
11	Overall heat transfer coefficient when clean (Uc)	$Uc = \frac{hioxho}{hio + ho}$	Eq.11
12	Overall heat transfer coefficient after operation (Ud)	$Ud = \frac{Q}{AxΔT}$	Eq.12
13	Fouling factor (Rd)	$Rd = \frac{Uc - Ud}{Uc\,x\,Ud}$	Eq.13

RESULTS

Table 4 shows that there is no significant difference in the initial heat transfer rate (Qin), the shell heat transfer coefficient (*h*0), the tube heat transfer coefficient (*h1),* and U_C. These data indicate that the same treatment occurred for the three samples. After processing for 110 minutes for the five batches, different results were obtained for Log mean temperature difference (LMTD). The Ud value is the average batch value at the beginning of the process (0 minutes) and the end of the process (110 minutes). The largest Rd value occurred in milk samples, and the smallest was in orange juice. The overall heat transfer coefficient after the operation (Ud) for the three samples can be seen in figure 2.

Table 4. Calculation results

Parameter	Unit	Orange	Avocado	Milk
$h0 = \varphi JH\,x\frac{k}{De}x(Pr)^{1/3}$	Btu/(hr) (ft²)(F)	3628.82	3633.98	3633.63
$hi = \varphi t.JHt\,x\frac{kt}{ID}x(Prt)^{1/3}$	Btu/(hr) (ft²)(F)	385.85	384.04	394.56
$LMTD = \frac{(T1-t2)-(T2-t1)}{ln((T1-t2)/(T2-t1)}$	°F	2.11	5.23	10.8
Qin= W.Cp (T1 - T2)	Btu/hr	190,858.01	190,798.34	183,871.61
$Uc = \frac{hioxho}{hio + ho}$	Btu/(hr) (ft²)(F)	356.05	357.01	356.06
$Ud = \frac{Q}{AxΔT}$	Btu/(hr) (ft²)(F)	8.59 - 47.089	21.47 - 117.72	42.95- 250.45
$Rd = \frac{Uc - Ud}{Uc\,x\,Ud}$	Hr. Ft². F / Btu	0.0003 - 0.0041	0.0007 - 0.0102	0.0014 – 0.0205

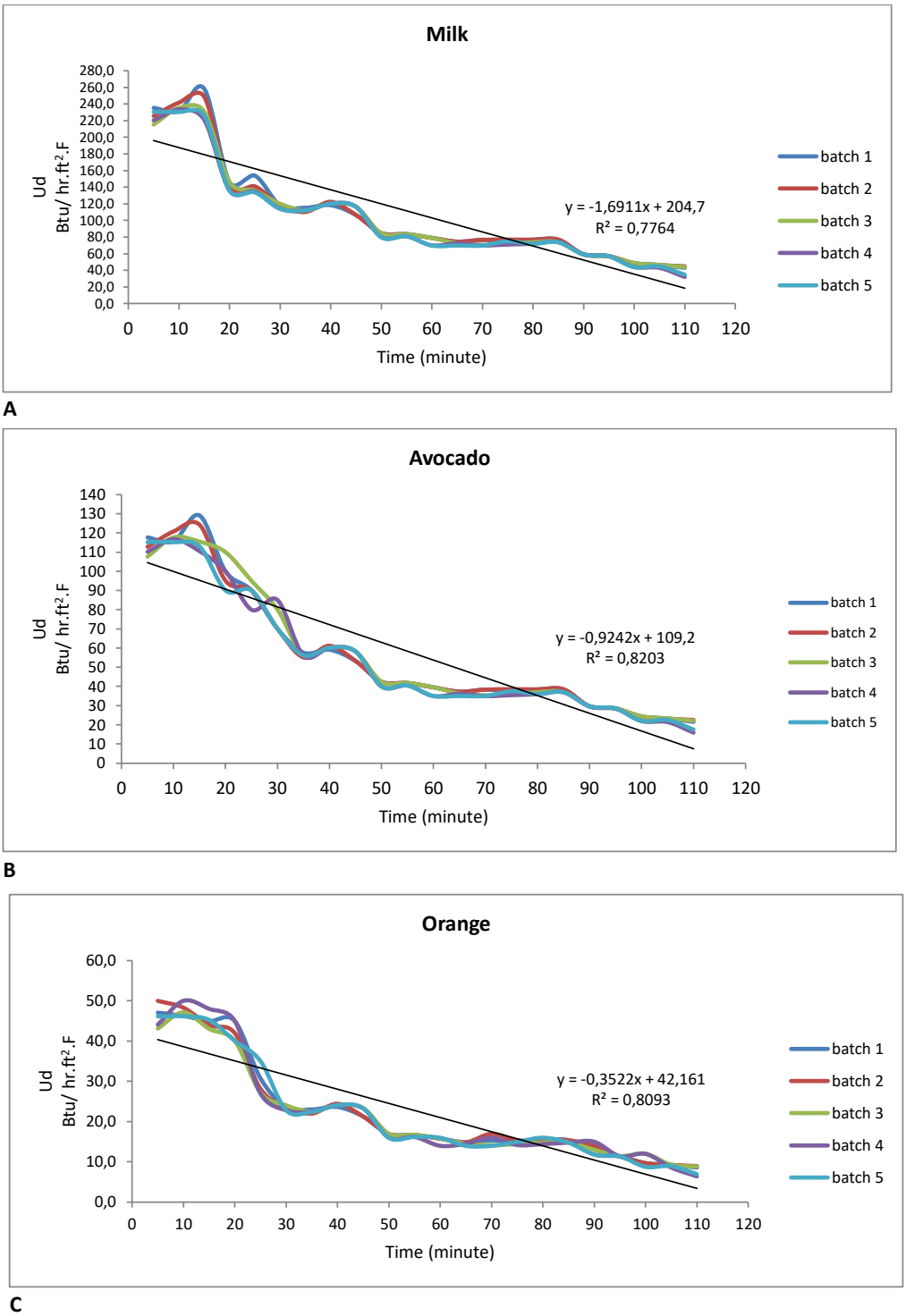


Figure 2. Overall heat transfer coefficient after operation (Ud)

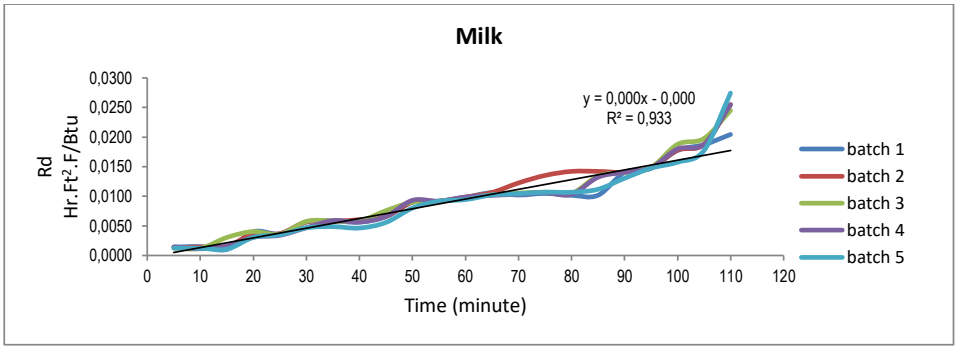
Ud in milk products (Fig.2A), avocado (Fig.2B), and orange (Fig.2C) at the beginning of the process at 1-10 minutes still shows a regular graph. In minute 15, there was an increase in Ud for milk and avocado. The chart experienced a steady decline despite an increase in minute 85. The decline continued until minute 110.

In figure 2, the three samples experienced the same condition, namely a regular decrease with the length of the process. The highest Ud range is still shown by milk, and the lowest is orange juice. Ud indicates the magnitude of the heat transfer rate (BTU/hour) per cross-sectional area (ft^2) and the temperature difference /ΔT (°F). The larger Ud value will reduce Rd in the HE area.

Referring to the Ud results, the following is the Rd value of each sample per minute. Figure 3 shows the same pattern; namely, there is a regular increase in each batch for milk, avocado, and orange products.

The Rd of milk (Fig.3A), avocado (Fig.3B), and Orange (Fig.3C) is inversely proportional to the value of Ud in each sample. There was the same decrease in minutes 80-90 for all three samples.

In figure 3, it can be seen that there is a significant difference in the value of Rd for the three samples. Dairy products have the highest rate of 1.7 $x10^{-4}$ hr. Ft^2. F / Btu in 1 minute. Avocado in the range 8.6 $x10^{-5}$ hr. Ft^2. F / Btu, while orange has the lowest rate of 3.4 $x10^{-5}$hr. Ft^2. F / Btu.



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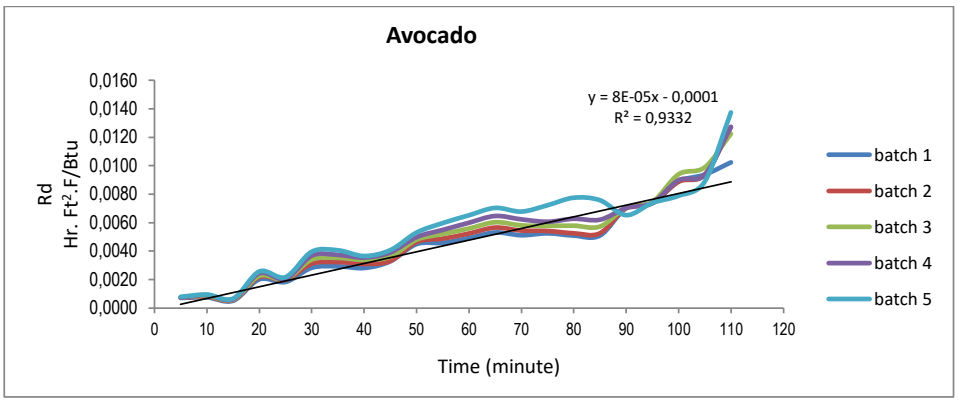

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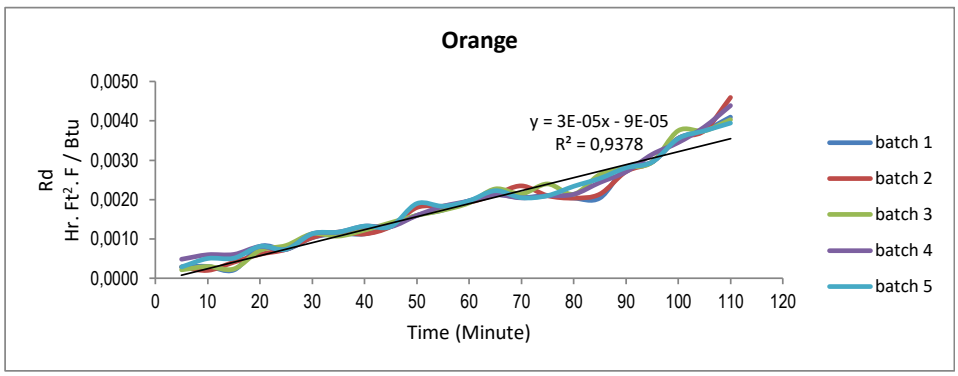

C

Figure 3. Rd value per time for the three samples

Figure 4, shows that the Rd value is directly proportional to the number of microorganisms in the sample that comes out of the HE area. Growth occurred at minutes 30-40 for milk products and avocado juice, while growth occurred at minutes 20-30 for orange juice. Bacterial growth (TPC) continued to increase while yeast & mold increased until minute 80 and sloped at minutes 90-110 for milk and avocado juice. In orange juice, bacterial growth continued to increase until minute 110, and yeast & mold growth increased so that the number exceeded the number of bacteria (TPC).

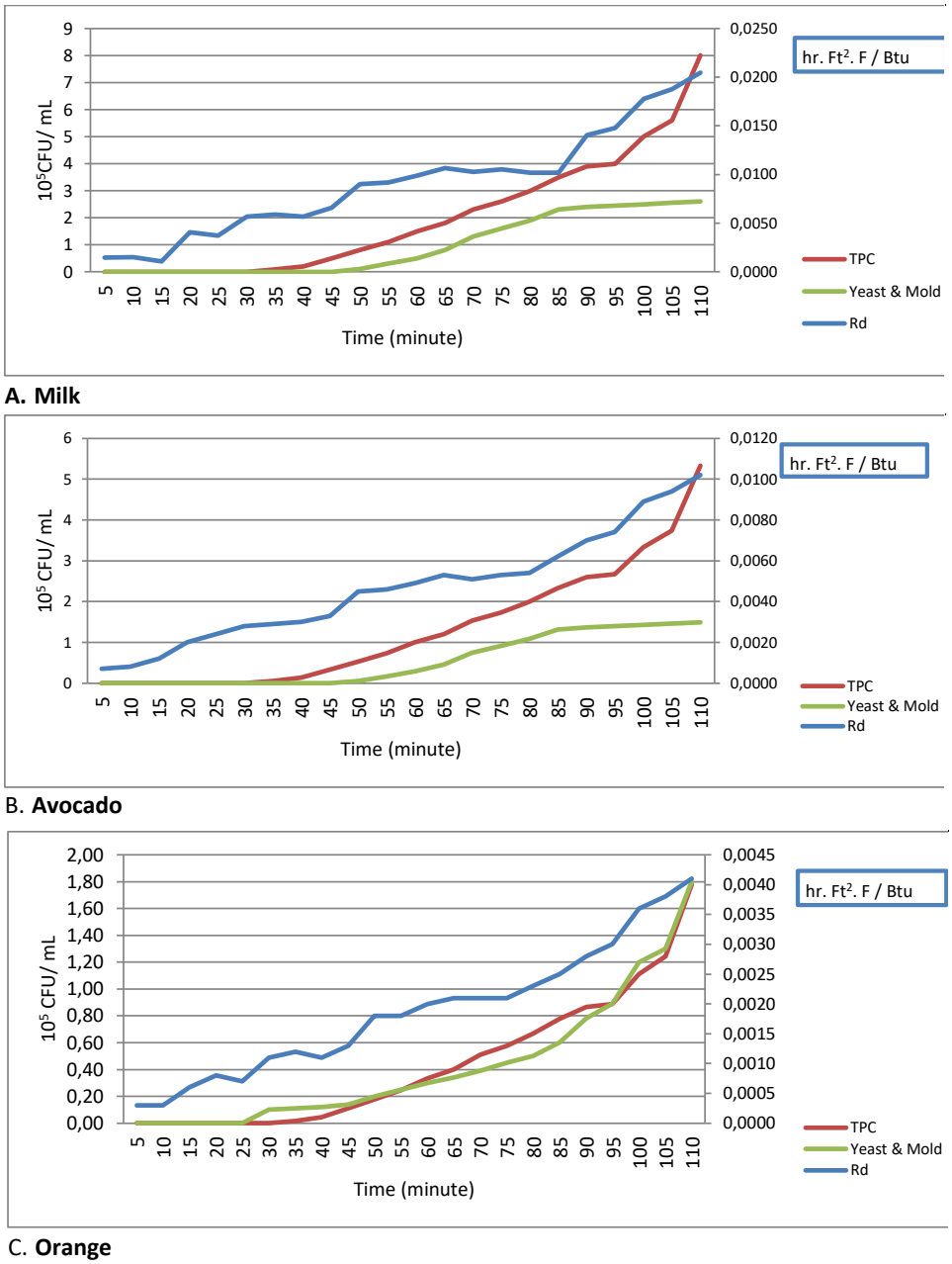

Figure 4. Relationship of Rd and the growth of microorganisms

A qualitative analysis was also carried out for the types of bacteria found in the fouling layer (Rd) attached to the pipe (deliberately removed to facilitate qualitative analysis of bacteria and chemical composition) (figure 4).

Table 5 shows that the types of bacteria living in milk are far more abundant when compared to avocado juice and orange juice. Staphylococcus bacteria were able to live in all three samples. All types of bacteria can live in milk drinks, including Actinomycetes, which are morphologically similar to yeast.

Table 5. Qualitative Test Results Bacteria attached to the sterilization tube.

NO	Microorganisms	Milk	Avocado	Orange
1	*Lactobacillus*	+		+
2	*Staphylococcus*	+	+	+
3	*Enterobactericeae*	+		+
4	*Micrococcus*	+		
5	*Corynebacterium*	+	+	
6	*Pseudomonas*	+	+	
7	*Actinomycetes*	+		
8	*Bacillus*	+	+	
9	*Streptococcus*	+		

The chemical composition of the Rd layer showed different results between milk and other samples (Table 6). In dairy products, there are found proteins (54.22%) and minerals 42.37%. The rest is fat and other components. Meanwhile, in avocado and orange juices, the mineral composition is more than protein, while fat is still in the range of 2%. Especially for minerals, dairy products are mostly calcium. There are potassium, magnesium, and phosphorus in avocado juice (potassium) and orange juice.

Table 6. Chemical composition of the Rd layer in the HE area

Milk						
Chemical Composition (% w/w)	**Qty**	**Minimum**	**Maximum**	**Mean**		**Std. Deviation**
	batch	**Statistic**	**Statistic**	**Statistic**	**Std. Error**	**Statistic**
Unsaturated fat	5	2.32	2.38	2.3440	.5671	1.268
Saturated fat	5	.03	.07	.0500	.0091	.0204
Protein	5	54.10	54.30	54.2200	.0911	.2038
Sodium	5	8.90	9.10	8.9800	.0099	.0221
Potassium	5	11.92	12.95	12.1720	.0229	.0511
Calsium	5	12.60	12.82	12.6980	.0331	.0741
Magnesium	5	2.11	2.20	2.1400	.0260	.0582
Phospor	5	3.45	3.75	3.5500	.1159	.2591
Chloride	5	1.60	1.80	1.7000	.1811	.4050
Etc, vitamin	5	1.10	1.40	1.2760	.1731	.3870
Avocado						
Chemical Composition (% w/w)	**Qty**	**Minimum**	**Maximum**	**Mean**		**Std. Deviation**
	batch	**Statistic**	**Statistic**	**Statistic**	**Std. Error**	**Statistic**
Unsaturated fat	5	2.23	2.30	2.2640	.1074	.2401
Saturated fat	5	.08	.18	.1380	.0051	.0114
Protein	5	44.70	44.98	44.8660	.1887	.4220
Sodium	5	11.84	11.96	11.9100	.0521	.1164
Potassium	5	11.90	12.20	12.0260	.0519	.1160
Calsium	5	8.90	9.00	8.9460	.0238	.0532
Magnesium	5	6.90	7.00	6.9680	.0242	.0542
Phospor	5	5.90	7.00	5.9460	.0287	.0641
Chloride	5	4.84	4.98	4.9360	.0382	.0855
Etc, vitamin	5	.94	1.10	1.0210	.0206	.0461
Orange						
Chemical Composition (% w/w)	**Qty**	**Minimum**	**Maximum**	**Mean**		**Std. Deviation**
	batch	**Statistic**	**Statistic**	**Statistic**	**Std. Error**	**Statistic**
Unsaturated fat	5	2.24	2.40	2.2840	.0734	.1642
Saturated fat	5	.38	.46	.4160	.0097	.0216
Protein	5	45.04	45.18	45.1160	.0681	.1522
Sodium	5	11.90	12.10	11.9800	.0809	.1810
Potassium	5	7.96	8.10	8.0260	.0520	.1162
Calsium	5	6.90	7.10	6.9540	.0242	.0541
Magnesium	5	8.20	8.40	8.3340	.0126	.0282
Phospor	5	8.88	9.01	8.9460	.0287	.0641
Chloride	5	3.90	3.96	3.9360	.0381	.0851
Etc, vitamin	5	1.98	2.08	2.0240	.0207	.0463

At the same sampling point, the protein content and Total Plate Count (TPC) were analyzed in the sterilization area pipe at the end of the process (the pipe was removed for easy analysis). Test the effect of the two variables (dependent and predictor) can be seen in table 7.

Table 7. Anova test for effect of microbial growth on protein content.

ANOVAa

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1983.924	2	991.962	1517.8	.000b
	Residual	4.576	7	.654		
	Total	1988.500	9			

a. Dependent Variable: Protein

b. Predictors: (Constant), Microbe, Time

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999a	.998	.997	.80854

a. Predictors: (Constant), Microbe, Time

A

ANOVAa

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1304.048	2	652.024	1940.948	.000b
	Residual	2.352	7	.336		
	Total	1306.400	9			

a. Dependent Variable: Protein

b. Predictors: (Constant), Microbe, Time

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999[a]	.998	.998	.57960

a. Predictors: (Constant), Microbe, Time

B

ANOVAa

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1974.211	2	987.106	1776.790	.000b
	Residual	3.889	7	.556		
	Total	1978.100	9			

a. Dependent Variable: Protein

b. Predictors: (Constant), Microbe, Time

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999a	.998	.997	.74536

a. Predictors: (Constant), Microbe, Time

C

There was a significant effect between the number of microbes on the protein content in the Rd layer ($p<0.05$). In table 7A, in the fouling layer of milk drinks, there was an increase in the number of microbes ($p = 0.000$) to the decrease in protein content. The variable number of microbes and time can simultaneously affect the protein content of 99.8%. Table 7B (avocado sample) showed that the number of microbes had an effect (99.8%) on protein content ($p<0.05$), and Table 7C (orange) showed that the number of microbes had an effect (99.8%) on protein content.

DISCUSSION

Comparing milk drinks, avocado juice, and orange juice to the formation of Rd in the HE area is an effort to make a sanitation schedule in the HE area. Figure 3 shows the formation of Rd in milk drinks is faster than in avocado juice and orange juice. In a matter of minutes, an Rd of 1.7 $x10^{-4}$ hr. Ft^2. F / Btu is formed. During the 110-minute process, the average Rd value was 0.0205 hr. Ft^2. F / Btu. The Rd value makes the average bacterial growth 8 x 10^5 CFU/ml, and the growth of yeast & molds reaches 2.2 x 10^5 CFU/ml. Meanwhile, for avocado juice, the formation of Rd per minute is around 8.6 $x10^{-5}$hr. Ft^2. F / Btu with bacterial contaminants at 110 minutes is 5.4 x

10^5 CFU/ml, and yeast and mold numbers are 1.5 x 10^5 CFU/ml. The lowest Rd formation was orange juice (3.4 x10^{-5}hr. Ft^2. F / Btu), but it caused almost the same bacterial growth as yeast & mold, 1.3 x 10^5 CFU/ml. Referring to the data above, The schedule for pipe cleaning in the sterilization area refers to the company's internal policy by choosing an efficiency of 95% HE (see table 2, Rd: 0.027- 0.035 Hr.Ft^2.F/Btu). Based on the data above, the researcher recommends a proper sanitation schedule for milk drinks every 110 minutes (one batch) or every 2 hours. The sanitation schedule for avocado juice is longer, at 4 hours. The longest sanitation time is for orange juice, which can be done every 10 hours of operation.

A comparison of raw material composition is used to see the chemical composition of the fouling layer (Rd) and to close the research gap related to the inconsistency of research results so far. Table 6 shows the chemical composition of the fouling layer (Rd) for milk drinks, with the largest percentage being protein, minerals, fats, and others. This condition is very different from the results in avocado juice and orange juice: minerals, protein, fats, and others. This study's results confirm previous researchers' findings [1–6]. If we examined the initial components of the sample, it shows that the milk component had a greater protein content among other samples (table 1), while avocado and orange juices had more mineral content. This demonstrated that the raw material components affect the components in the fouling layer (Rd).

Fouling occurs due to the development of microorganisms in the HE area, also known as biofouling. Bott's research [22] and Flint *et al.* [14,23,24] emphasized two mechanisms for the formation of biofouling which have become a well-established concept until now, namely the accumulation of microorganism growth in the fouling layer and the attachment of microorganisms to the outermost layer of fouling. Therefore, microbial contamination is caused by the sterilization process in the HE that is not optimal (innate microbes do not die), and microbes that grow in the fouling layer are carried away by the product flow. Figure 4 and Table 7 show the progress of biofilm formation, in which this study focuses more on the effect of microbial growth on protein content. This is motivated by the well-established concept that "protein is a nutrient for microbial growth".

This study showed that microbial contamination is caused by innate microbes and a non-optimal sterilization process that renders a fouling layer along the HE pipe and extends to the distribution pipe. Fouling that sticks along the pipe is a potential for the growth of microbes, so product contamination cannot be avoided. Milk drinks dominate the type of bacteria that grow because their components are rich in chemicals for microbial growth. This is inversely proportional to avocado and orange juice, dominated by only a few types of bacteria.

Making a correlation between chemical composition (protein) and the rate of microbial growth provides an understanding that the growth of these microbes largely determines the composition of the fouling layer in the sterilization area. Determining the chemical composition of the fouling layer should be wiser by looking at microbial growth. Research conducted without looking at microbial growth by previous researchers [9,12,13] will prolong the debate regarding the chemical composition of the fouling layer (Rd).

CONCLUSION

Comparison of the composition of raw milk, avocado juice, and orange juice helps in understanding:

1. The rate of formation of the fouling layer (Rd) to assist in making a sanitation schedule in the sterilization area. The results showed that the sanitation schedule for milk (2 hours) was shorter than that of avocado juice (4 hours) and orange juice (10 hours);
2. The chemical composition of beverage raw materials affecting the composition of the fouling layer (Rd) that sticks along the distribution pipes;
3. A strong influence between microbial growths on the composition of the fouling layer (protein) that can close the research gap related to the inconsistency of previous research results (fouling layer composition) so that there is no prolonged debate.

NOMENCLATURE

Symbol	Name, Units	Symbol	Name, Units
c	Index for cold fluid	σ	proportional constant (BTU/hour ft^2 ^0C)
s	Index for shell part	m	flow rate of hot fluid flow (lb/hour)
t	Index for tube section	Cp	specific heat coefficient (BTU/lb ^{0} F)
Q	Heat transfer rate (BTU/hour)	Fc	caloric fraction
K	Thermal conductivity (BTU/hour)	ID	inside diameter (ft
A	Cross-sectional area of heat transfer (ft^2)	OD	outside diameter (in)
T	Temperature (°F)	C	distance between tubes (in)
x	Heat flow path distance (ft)	B	distance between baffles (in)
h	Heat transfer coefficient (BTU/hour ft^2 ^0C)	P	pitch (in)
e	Emissivity (0 to 1)	a	flow area (ft^2)
Nt	number of tubes	N	number of passes
G	fluid flow pressure (lb/ ft^2)	De	equivalent diameter (ft)
μ	viscosity (lb/hr ft)	φ	Rasio of viscosity
*hi*0	the shell heat transfer coefficient Btu/(hr) (ft^2)(F)	*h*0	the tube heat transfer coefficient Btu/(hr) (ft^2)(F)
Prs	prandl number in shell	Prt	prandl number in tube
JHs	Heat transfer factor in shell	JHt	Heat transfer factor in tube
W	Mass flowrate of fluid (kmol/hr)	LMTD	Log mean temperature different (^{0} F)
G	Mass Flow Rate	Uc	Overall heat transfer coefficient when clean (Btu/ hr.ft2.F)
Ud	Overall heat transfer coefficient after operation (Btu/ hr.ft2.F)	$(\frac{h}{\varphi})$	Heat Transfer Coefficient
tw	Temperature on the tube wall (^{0}F)	Rd	Fouling factor (Hr. Ft2. F / Btu)

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