Kasetsart J. (Nat. Sci.) 40 : 215 - 222 (2006)

Comparative Efficiency of KU and ISO Plungers in Mixing Composite Bulk Raw Milk

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ABSTRACT

The study was conducted to investigate the best mixing indicators among the milk composition i.e. milk protein, fat and SNF and to determine the efficiency of two plungers, i.e. Kasetsart University (KU) and International organization for standardization (ISO) for raw milk truck. Fat content was found to be the best indicator for mixing milk prior to sampling. Fat content stabilized after 10, 5 and 10 times of stirring raw milk truck's chamber I, II, and III of 4,700, 3,900 and 7,400 kg capacities respectively; whereas the protein and SNF stabilized after 5 times of stirring irrespective of the chamber sizes in the study. Significant difference ($p<0.05$) was observed in the efficiency of the two types of plunger in mixing milk. Using milk fat as indicator, the KU designed plunger was found to be more efficient in mixing for the small chambers. However, when compared to ISO plunger there was no difference in mixing efficiency for the larger chamber. Statistically, the milk mixed with KU plunger attained homogeneity after 5 times of stirring in all the chambers; whereas the milk mixed with ISO standard plunger attained homogeneity only after 15 times of stirring for chamber I and II and 10 times of stirring for the chamber III. However, using the criteria of maximum variation of plus or minus 0.1% level between the mixing intervals to obtain representative samples at least 15 times of stirring for chamber I and II, and 20 times of stirring for chamber III for KU plunger would be required prior to sampling. Whereas, 20 times of stirring for ISO plunger would be necessary prior to sampling for all the chambers with capacity of less than 7,400 kg.

Key words: mixing efficiency, raw milk truck, KU and ISO standard plunger, milk composition

INTRODUCTION

Milk fat and SNF have been widely used as the indicator for raw milk composition quality (Hasanuzzaman *et al.*, 2002). Milk fat is the oldest and most widespread compositional payment criteria adopted. However, increasing trend towards adopting crude protein level as the basis for raw milk payment was evident (Harding, 1995; Hurley, 2004). This is due to the health concerned parallel to the demand for higher yield of milk products, especially cheese. Obtaining representative milk sample and its subsequent proper handling are keys to reliable results for quality and compositional analysis. This could be achieved after adequate agitation of milk, which

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Received date : 12/10/05 Accepted date : 05/01/06

is constrained mainly due to factors, i.e., the wide variety of style and design of tanks, methods of agitation, volume of the products held and types of milk agitators (Grace *et al.*, 1992). This problem was further aggravated by the creaming phenomenon, which in a tank was said to depend on the time that has elapsed from the completion of cooling of the milk until it was agitated for sampling (Likas and Calbert, 1954). Therefore, it is necessary to determine the adequate agitation time for the individual tank prior to sampling. However, there are no prescribed international standards on mixing length, besides the general consensus that the adequate agitation times are five minutes for tanks under 1,000 gallons and 10 min for tanks of 1,000 gallons and more (Goodridge *et al.*, 2004). Such a long duration of mixing would not be necessary, considering the improvement in management of milk handling and transportation system. Several agitation methods, i.e. manual, mechanical and air compressor were adopted. In most developed countries milk trucks were installed with mechanical agitator and milk during transportation were periodically agitated, thereby reduced the time of agitation prior sampling. However, impacts of intermittent mixing on the quality of milk were not studied (Goodridge *et al.*, 2004).

In Thailand no regulation exists on the standard requirement for the bulk milk trucks. As such most raw milk trucks are not furnished with mechanical agitator. Therefore no intermittent mixing of milk takes place during transportation. Thus, obtaining representative sample at the dairy plant fully depended on the efficiency of manual plunging. Different types of locally designed plunger are adopted in mixing milk prior to sampling. This could be due to limited information available on the efficiency of ISO standard plunger. Therefore, this study was planned to investigate the best milk composition to be adopted as mixing indicator and also to compare the efficiency of KU designed versus the ISO standard plungers.

MATERIALS AND METHODS

The experiment was conducted on the chambers of bulk milk truck delivering raw milk to KU Dairy Center after approximately 3.5-4 hrs of transportation from Milk Collection Center (MCC). The capacity of the chambers was 4,700 kg, 3,900 kg, and 7,400 kg for chamber I, II and III respectively. Two different plungers with following specification were used; a) the ISO standard made of stainless steel rod of 2 m in length, fitted with a 300 mm diameter disc

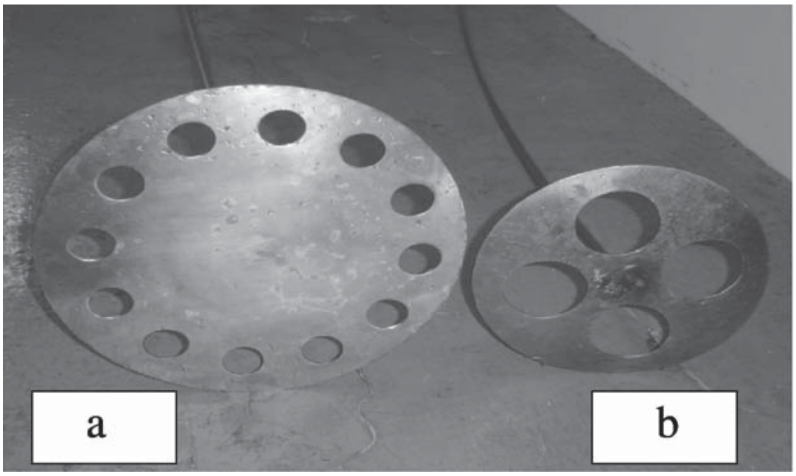

Figure 1 Different manual plungers; a) ISO standard and b) KU.

perforated with 12 holes each 30 mm in diameter on a circle of 230 mm in diameter from the center (ISO/FDIS, 1997) and b) the KU design made of stainless steel rod of 1.80 m in length, fitted with a stainless disc of 230 mm in diameter perforated with 4 holes each 62 mm in diameter on a circle of 205 mm in diameter from the centre.

Raw milk samples

Prior to transferring milk from the truck to storage tank, milk from each chamber was mixed at uniform interval of 0, 5, 10, 15, 20, 25 and 30 times of stirring using both plungers. During each sampling time, 60 ml of raw milk were collected in plastic bottles of 80 ml capacity with the help of plastic jug from the top opening of each chamber. Samples were collected from all three chambers adopting the similar method and were analyzed for fat content and other milk compositions at the laboratory using calibrated ultrasonic milk analyzer, Ekomilk-M (Eon Trading, 2001).

Statistical analysis

Data were analyzed under a split plot in Completely Randomized Design (CRD) using PROC GLM in SAS. The statistical model used was

$$Yijkl = \mu + \rho i + \delta k(i) + \alpha j + \beta(\rho)il + \rho\alpha ij + \varepsilon ijkl$$

where Yijkl was the dependent variable; μ was the overall mean; ri was the effect of chambers as main plots (i = 1, 2, 3), $\delta k(i)$ was the main plot error; αj was the effect of stirrers (j = 1, 2); βl was the effect of stirrers (l = 1 and 2); $\beta(\rho)il$ stirring times nested with containers; $\rho\alpha ij$ was the interaction effect between the plunger and container, and $\varepsilon ijkl$ was the subplot error at NID $(0, \sigma e^2)$.

Statistical differences among different stirring times were analyzed using Duncan's multiple range test (DMRT) according to Cody and Smith (1997).

RESULTS AND DISCUSSION

Milk composition

The changing analysis values of milk composition sampling at various stirring times are illustrated in Table 1-3 for protein, solid-not fat (SNF) and fat respectively. The protein and SNF content in milk mixed with both plungers, stabilized after 5 times of stirring with no significant differences ($p>0.05$) with the rest of stirring times (Table 1 and 2), whereas the milk fat content statistically stabilized only after 10, 5 and 10 times of stirring for chamber I, II and III respectively (Table 3). The shortest time to attain homogeneity in protein content could be explained by its nature of existence in dispersion form of a very tiny particle size ranging from 10^{-4} to 10^{-5}mm (Tetrapak, 1995), which could be easily disturbed and redistributed with mild agitation. Whereas, early stabilization of SNF could be explained by early stabilization of protein, which was one of the SNF components and the other water soluble components of SNF, i.e. lactose, minerals and certain vitamins which existed in true solution. The early stabilization of protein and SNF could also be in part explained by the nature of variation of milk components, where fat showed the widest variation, followed by protein, lactose and then ash (Table 4) (Jenness, 1988). The difficulty in stabilization of fat content was caused by stratification of fat globules during storage or transportation from gravity creaming and also from the action of cold agglutinin. Fat globule tended to float due to lower density as compared to skim milk; depleting the fat content at the lower portion of the container forming cream layer at the surface. Creaming was reported to onset after 40-50 minute of milk holding after cooling to 5 °C (Goodridge *et al.*, 2004).

Comparative plunger efficiency

Comparative effectiveness of KU versus ISO standard designed plungers using protein, SNF and fat composition in raw milk as indicators are illustrated in Table 5-7. Using both types of plunger, protein and SNF stabilized after 5 times of agitation (Table 5 and 6). Milk fat content also attained homogeneity ($p<0.05$) after 5 times of stirring with KU plunger in all three chambers, whereas, milk mixed with ISO standard required 15 times of stirring for chamber I and II, and 10 times for the chamber III (Table 7). The statistical inferences of the shortest stirring times for the two plunger designs with different chamber capacities of milk truck tank were not practically acceptable

Table 1 Least square means ±SE for protein (%) as an indicator for adequate mixing of raw milk in different chambers.

Stirring number	Chamber I	Chamber II	Chamber III
0	2.78 ± 0.033^{b}	2.63 ± 0.033^{b}	2.67 ± 0.033^{b}
5	3.05 ± 0.033^{a}	3.07 ± 0.033^{a}	3.06 ± 0.033^{a}
10	3.06 ± 0.033^{a}	3.07 ± 0.033^{a}	3.07 ± 0.033^{a}
15	3.07 ± 0.033^{a}	3.07 ± 0.033^{a}	3.06 ± 0.033^{a}
20	3.08 ± 0.033^{a}	3.08 ± 0.033^{a}	3.07 ± 0.033^{a}
25	3.07 ± 0.033^{a}	3.08 ± 0.033^{a}	3.08 ± 0.033^{a}
30	3.08 ± 0.033^{a}	3.07 ± 0.033^{a}	3.07 ± 0.033^{a}

N of individual stirring number for each chamber = 20.

ab Means with different superscripts within the same column are significantly different ($p<0.05$).

Table 2 Least Square means ±SE of SNF (%) as an indicator for adequate mixing of raw milk in different chambers.

Stirring number	Chamber I	Chamber II	Chamber III
0	7.19 ± 0.095^{b}	6.72 ± 0.095^{b}	6.86 ± 0.095^{b}
5	8.04 ± 0.095^{a}	8.10 ± 0.095^{a}	8.08 ± 0.095^{a}
10	8.07 ± 0.095^{a}	8.11 ± 0.095^{a}	8.11 ± 0.095^{a}
15	8.12 ± 0.095^{a}	8.11 ± 0.095^{a}	8.10 ± 0.095^{a}
20	8.14 ± 0.095^{a}	8.14 ± 0.095^{a}	8.12 ± 0.095^{a}
25	8.13 ± 0.095^{a}	8.14 ± 0.095^{a}	8.13 ± 0.095^{a}
30	8.14 ± 0.095^{a}	8.13 ± 0.095^{a}	8.13 ± 0.095^{a}

N of individual stirring number for each chamber = 20.

ab Means with different superscripts within the same column are significantly different ($p<0.05$).

Table 3 Least Square means ±SE for fat content (%) as an indicator for adequate mixing of raw milk in different chambers.

Stirring number	N	Chamber I	N	Chamber II	N	Chamber III
0	15	9.55 ± 0.170^{a}	12	9.63 ± 0.188^{a}	20	9.58 ± 0.182^{a}
5	20	5.15 ± 0.157^{b}	20	4.47 ± 0.157^{b}	20	4.96 ± 0.157^{b}
10	20	4.81 ± 0.157^{bc}	20	4.33 ± 0.157^{b}	20	4.24 ± 0.157^{bc}
15	20	4.12 ± 0.157^{c}	20	4.20 ± 0.157^{b}	20	4.19 ± 0.157^{bc}
20	20	4.02 ± 0.157^{c}	20	4.02 ± 0.157^{b}	20	4.03 ± 0.157^{c}
25	20	3.95 ± 0.157^{c}	20	3.96 ± 0.157^{b}	20	4.03 ± 0.157^{c}
30	20	3.98 ± 0.157^{c}	20	3.98 ± 0.157^{b}	20	3.99 ± 0.157^{c}

abc Means with different superscripts within the same column are significantly different ($p<0.05$).

Table 4 Variations in the composition of raw milk.

Samples		Trocher (1925) 676 individual milking	Overman *et al.* (1939) 2426 3-day composites	Herrington *et al.*(1972) 868 bulk tank
Fat (%)	Mean	3.95	4.37	3.53
	SD	0.78	0.82	0.28
	CV	0.20	0.19	0.08
Crude	Mean	3.24	3.74	3.13
Protein (%)	SD	0.40	0.52	0.14
	CV	0.12	0.14	0.05
Lactose (%)	Mean	4.64	4.89	4.82
	SD	0.37	0.38	0.16
	CV	0.08	0.08	0.03
Ash (%)	Mean	0.70	0.72	0.72
	SD	0.05	0.05	0.01
	CV	0.07	0.07	0.02
Total solid (%)	Mean	-	13.73	12.02
	SD	-	1.23	0.63
	CV	-	0.09	0.05

Sources: Compiled by Jenness (1988).

Table 5 Least Square means ±SE of protein (%) used as indicator for the efficiency of plungers.

Stirring number	Chamber I		Chamber II		Chamber III	
	KU	ISO	KU	ISO	KU	ISO
0	2.69 ± 0.05^b	2.81 ± 0.04^b	2.43 ± 0.05^b	2.57 ± 0.05^b	2.72 ± 0.04^b	2.45 ± 0.06^b
5	3.07 ± 0.05^a	3.03 ± 0.04^a	3.08 ± 0.05^a	3.08 ± 0.05^a	3.05 ± 0.04^a	3.09 ± 0.06^a
10	3.08 ± 0.05^a	3.05 ± 0.04^a	3.08 ± 0.05^a	3.08 ± 0.05^a	3.05 ± 0.04^a	3.09 ± 0.06^a
15	3.08 ± 0.05^a	3.05 ± 0.04^a	3.07 ± 0.05^a	3.08 ± 0.05^a	3.06 ± 0.04^a	3.08 ± 0.06^a
20	3.09 ± 0.05^a	3.05 ± 0.04^a	3.08 ± 0.05^a	3.09 ± 0.05^a	3.08 ± 0.04^a	3.08 ± 0.06^a
25	3.08 ± 0.05^a	3.06 ± 0.04^a	3.08 ± 0.05^a	3.09 ± 0.05^a	3.08 ± 0.04^a	3.09 ± 0.06^a
30	3.08 ± 0.05^a	3.08 ± 0.04^a	3.07 ± 0.05^a	3.08 ± 0.05^a	3.08 ± 0.04^a	3.09 ± 0.06^a

N of individual stirring number for each chamber = 10.

[ab] Means with different superscripts within same column are significantly different ($p<0.05$).

Table 6 Least Square means ±SE of SNF (%) used as an indicator in for the efficiency of plungers.

Stirring number	Chamber I		Chamber II		Chamber III	
	KU	ISO	KU	ISO	KU	ISO
0	6.92 ± 0.13^b	7.26 ± 0.12^b	7.85 ± 0.06^b	6.13 ± 0.13^b	6.92 ± 0.12^b	6.13 ± 0.13^b
5	8.12 ± 0.13^a	7.96 ± 0.12^a	8.13 ± 0.06^a	8.10 ± 0.13^a	8.05 ± 0.12^a	8.10 ± 0.13^a
10	8.16 ± 0.13^a	8.04 ± 0.12^a	8.13 ± 0.06^a	8.11 ± 0.13^a	8.06 ± 0.12^a	8.11 ± 0.13^a
15	8.16 ± 0.13^a	8.04 ± 0.12^a	8.16 ± 0.06^a	8.11 ± 0.13^a	8.11 ± 0.12^a	8.11 ± 0.13^a
20	8.19 ± 0.13^a	8.05 ± 0.12^a	8.15 ± 0.06^a	8.13 ± 0.13^a	8.16 ± 0.12^a	8.13 ± 0.13^a
25	8.18 ± 0.13^a	8.06 ± 0.12^a	8.16 ± 0.06^a	8.13 ± 0.13^a	8.17 ± 0.12^a	8.13 ± 0.13^a
30	8.17 ± 0.13^a	8.07 ± 0.12^a	8.16 ± 0.06^a	8.12 ± 0.13^a	8.16 ± 0.12^a	8.12 ± 0.13^a

N of individual stirring number for each chamber = 10.

[ab] Means with different superscripts within the same column are significantly different ($p<0.05$).

in terms of both manual sampling management and the relatively large variable of milk composition values between different intervals. The difference of analytical values are far beyond the acceptable range recommended by Grace *et al.* (1992) that " adequate agitation is that degree of agitation which, at full tank capacity, results in a variation in fat content of the milk in the tank of not more than ± 0.1 % level as determined by an official AOAC milk fat test". Adhering to the above recommendation by using the variable of fat composition as indicator, a trend requiring different mixing times for different chambers were evident in milk agitated with the two plungers (Table 8). More stirring times with the increase in the sizes of the chambers were observed. Milk in Chamber I and II agitated with KU plunger attained homogeneity after 15 times of stirring, whereas 20 times of stirring was required for chamber III (Table 9). Similar trend requiring more times to mix the milk homogeneously as the volume of milk in the tank increases were observed (Likas and Calbert, 1954). This might be due to small surface area of the disc which in turn could not produce sufficient disturbances to disperse the clustered milk fat that was formed during transportation time. The plunger should be long and the disc should be large enough to provide sufficient disturbances during mixing (ISO/FDIS, 1997). On the other hand, the milk agitated with

Table 7 Least square means ±SE of fat content (%) as indicator in for the efficiency of different plungers.

Stirring	Chamber I				Chamber II				Chamber III			
number	N	KU	N	ISO	N	KU	N	ISO	N	KU	N	ISO
0	7	9.71 ± 0.31^{a}	8	9.87 ± 0.20^{a}	4	9.43 ± 0.41^{a}	10	9.33 ± 0.20^{a}	10	9.40 ± 0.28^{a}	10	9.66 ± 0.24^{ax}
5	10	4.72 ± 0.26^{bc}	10	5.51 ± 0.18^{b}	10	4.44 ± 0.26^{b}	10	4.91 ± 0.17^{b}	10	4.49 ± 0.26^{b}	10	4.98 ± 0.24^{b}
10	10	4.31 ± 0.26^{c}	10	4.58 ± 0.18^{c}	10	4.30 ± 0.26^{b}	10	4.60 ± 0.17^{b}	10	4.40 ± 0.26^{b}	10	4.65 ± 0.24^{bc}
15	10	3.97 ± 0.26^{c}	10	4.29 ± 0.18^{cd}	10	4.02 ± 0.26^{b}	10	4.24 ± .17^{cd}	10	4.18 ± 0.26^{b}	10	4.32 ± 0.24^{c}
20	10	3.86 ± 0.26^{c}	10	4.15 ± 0.18^{d}	10	3.99 ± 0.26^{b}	10	4.13 ± 0.17^{d}	10	3.95 ± 0.26^{b}	10	4.07 ± 0.24^{c}
25	10	3.83 ± 0.26^{c}	10	4.09 ± 0.18^{d}	10	3.97 ± 0.26^{b}	10	4.10 ± 0.17^{d}	10	3.85 ± 0.26^{b}	10	4.05 ± 0.24^{c}
30	10	3.89 ± 0.26^{c}	10	4.06 ± 0.18^{d}	10	3.98 ± 0.26^{b}	10	4.04 ± 0.17^{d}	10	3.88 ± 0.26^{b}	10	4.05 ± 0.24^{c}

[abc] Means with different superscripts within the same column are significantly different ($p<0.05$).

Table 8 Least Square means ±SE of milk composition (%) used for the efficiency of plungers in mixing raw milk.

Chamber	Plunger	N	Protein	N	SNF	N	Fat
I	KU	70	3.02 ± 0.02	70	7.98 ± 0.05	65	4.91 ± 0.08
	ISO	70	3.02 ± 0.02	70	7.93 ± 0.05	70	5.25 ± 0.09
	p-value		0.7273		0.3951		0.0063
II	KU	70	3.06 ± 0.017	70	8.10 ± 0.050	66	4.79 ± 0.09
	ISO	70	2.98 ± 0.017	70	7.83 ± 0.050	70	5.09 ± 0.08
	p-value		0.0016		0.00002		0.0852
III	KU	70	3.01 ± 0.018	70	7.95 ± 0.050	70	4.95 ± 0.09
	ISO	70	3.00 ± 0.021	70	7.87 ± 0.050	70	5.06 ± 0.08
	p-value		0.5397		0.2991		0.0784
Average	KU	70	3.03 ± 0.010	70	8.01 ± 0.03	67	4.88 ± 0.05
Average	ISO	70	3.00 ± 0.010	70	7.88 ± 0.03	70	5.13 ± 0.05
	p-value		0.0187		0.0012		0.00004

Table 9 Difference in mean between the fat test (%) of different mixing times with that of composite fat test for all chambers.

Stirring number	Chamber I		Chamber II		Chamber III	
	KU	ISO	KU	ISO	KU	ISO
0	5.82	5.81	5.45	5.29	5.52	5.61
5	0.83	1.45	0.46	0.87	0.61	0.93
10	0.42	0.52	0.32	0.56	0.52	0.6
15	0.08	0.23	0.04	0.2	0.3	0.27
20	-0.03	0.09	0.01	0.09	0.07	0.02
25	-0.06	0.03	-0.01	0.06	-0.03	0
30	0	0	0	0	0	0

ISO standard plunger attained homogeneity of milk after 20 times of stirring for all chambers. More time of stirring required to mix the milk in the small chamber could be attributed to the inconvenience encountered during mixing motion of the plunger with large disc diameter. The occasional contact of plunger to the side surface of the tanks while mixing resulted in non uniformity of mixing cycles. On the other hand, the increase in stirring time of KU plunger for large chamber was attributed to its short stirring rod. A more complete mixing motion diameter could be attained with a slight improvement of its length. This emphasized that the proportionality of plunger to the size of containers was imperative for effective mixing.

CONCLUSIONS

Among the three milk constituents determined for attaining homogeneity in mixing raw milk prior to sampling, milk fat was found to be the best indicator. Comparing KU versus ISO designed plungers for manually mixing milk in the milk truck chamber prior to sampling, the KU plunger performed relatively better for small size milk chamber. However, both plungers were equal in their effectiveness in mixing milk for larger chamber. With slight increase in the length of the KU plunger rod, at least 15 times of proper stirring motion were required for chamber of less than 7,500 kg capacity. As for the ISO standard plunger, at least 20 times of stirring are required for similar sample homogeneity.

ACKNOWLEDGEMENTS

The authors would like to thank the staffs and management of KU Dairy Centre, Bangkok 10900, Thailand for their kind supports and Swiss Development Corporation, Helvetas and Royal Government of Bhutan for the financial supports.

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