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Pulsed Electric Fields Pasteurization of Milk: Effects of Various Voltage and Treatment Time on Physical Properties

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ABSTRACT

Pasteurized process of milk with pulsed electric fields with (PEF) various voltage and treatment time has been studied experimentally. The main concern of this research is to observe the effect of various voltage and treatment time on physical properties of milk. The PEF treatment was carried out using PEF laboratory unit, set with three levels of treatment voltage (i.e. 60 kV; 80 kV; and 100 kV) and performed in three different treatment duration (i.e. 10 s; 20 s; and 30 s). Effect s of variables of both treatments on density, viscosity, water content, boiling point, freezing point, turbidity level, red level (a+), and yellow level (b+) were investigated. The applied higher voltage and treatment duration has no significant effect on viscosity, density and water content. The boiling point, freezing point, turbidity level, red level (a+) and yellow level (b+) did not change significantly among the variety of the applied voltage. In general, these measured variables were less affected by the PEF treatment.

KEY WORDS: Milk; Pulsed Electric Fields (PEF); Physical Properties.

1. INTRODUCTION

In recent years, the common treatment in preservation milk is thermal process that using temperature between 60-100ºC, such as pasteurization and sterilization [1][2][3]. This process is used to lengthen the product storage life by inactivating the enzyme and degrading the microorganism in the milk [4][5]. During the thermal process of food, a large amount of energy is transferred into the food. This energy likely will cause undesired reacting, such as vitamin and essential nutrition loss and change of color, aroma and taste [2][3]. This phenomenon shows that both storage life and quality are two important things for the consumers.

One of the alternatives in preservation of food is using non-thermal process, with high voltage pulse or pulse electric field (PEF). PEF is one of the non-thermal processes using high voltage pulse. PEF can be applied for liquid food product, such as syrup, milk, soup and liquid egg [6]. This process uses a very short time treatment from microsecond to millisecond with short pulse. According to [7][6], the application of high voltage will inactivate the microorganism without creating any negative effect, especially to the aroma, taste and nutrition as if it is treated by a thermal process.

PEF process is based on short pulse application in high voltage (20-80kV/cm) to the food product that is located between two electrodes, PEF is a non-thermal process as the product is processed under an ambient temperature or below for several second. It is able to minimize nutrition loss due to a thermal treatment [8][6]. The effect of the pulse electric field depends on the power of the electric field as well as the application duration. The mortality effect is also a function of fluidal temperature that undergoes treatment due to the friction energy that is generated by the electric current [9].

Some of important parameters in PEF treatment are the electricity shocking power, pulse width, number of pulse and the design of the treatment chamber. According to [10], a bacterial cell membrane will be will be destroyed when get an electricity shock greater than 25 kV/cm with the pulse width between 100-200ns. The electricity shocking power depends on the applied high voltage pulse to the chamber, while the pulse number depends on the treatment duration [11]. To get the desired electricity shock for inactivating the microorganism, an adjustment of the high voltage pulse level was required.

The high voltage pulse is generated by the high voltage pulse generator. Several types of bacteria in any particular media need a certain process parameter, i.e. electricity shock and certain process duration to increase its effectiveness in inactivating the microbes. Hence, a voltage adjustment is needed in PEF. According to [12], the high voltage pulse generator with high voltage transformator (HV) have a high efficiency and also flexible in adjusting the output voltage.

Previous research work has shown that Pulsed Electric Field (PEF) can be used to avoid the physical degradation of food. Using various voltage and treatment time can increase the effectiveness of Pulsed Electric

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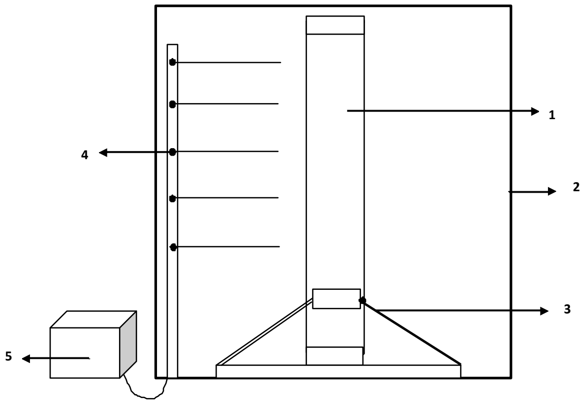
Field. Therefore, the increase of voltage and treatments time need laboratory test prior good amount of various physical properties towards good preservation of fresh milk. Following the problem formulation, the objectivities of the work is to examine the effects of various voltages and treatment time on physical changes i.e. density, viscosity, water content, boiling point, freezing point and color.

2. MATERIALS AND METHODS

The experiments were performed with laboratory-sized scale pulse generator designed by [13]. The gap distance between electrodes and treatment chamber volume was 5 mm and 1.7 × 106 mm3, respectively. The treatment temperature was kept on room temperature (below 35º C). The treatment chamber was made of a cylindrical stainless steel with 4 mm of width. All the PEF chamber and electrodes were located in the protection box which was made of mica plastic with 35 × 35 × 55 cm of dimension. A protection box made of mica was installed outside the chamber to protect the whole gadget as well as the operator. The thickness of this mica was 4 mm and 5 mm for its base. The thicker base was made in order to be able to support the treatment chamber and its content. The principle design is shown schematically in Fig. 1.



Components:

1. Treatment Chamber
2. Protection Box
3. Buffer with Ground
4. Electrodes
5. High Voltage Generator Box

Fig. 1. *The PEF Equipment*

In this study, the high voltage generator box consist of microcontroller as controller, LCD as display, keypad as input, flyback converter and high voltage transformer. Microcontroller is controller, which makes fixed frequency, constant pulse voltage and timers. Timer can be set to pass keypad as processing time, limits on and off period for switching component. In this way, the PEF device can be controlled and processing time can be set by using 8535 IC. The processing time can be set from the keypad and will be displayed on LCD (Liquid Crystal Display).

The driver receives pulses which produced by microcontroller and it is used to drive switching components. The switching components are use power transistor and OT transformer as connector switches between HV transformer and microcontroller as the regulator. HV transformer is a step up transformer which will increase the voltage. The output voltage of HV transformer is in form of high voltage pulse which depends on output pulse through switching circuit. High voltage pulse produced is then connected to two electrodes placed in the chamber. The principle design of high voltage generator box is shown schematically in Fig. 2.

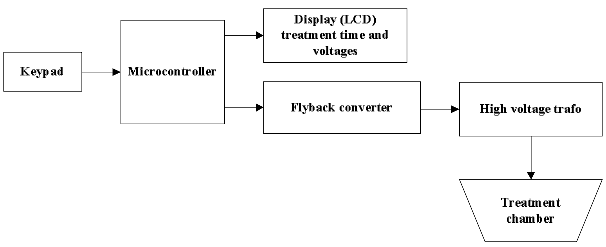


Fig. 2. *Schematic Diagram of High Voltage Generator*

Density was measured from approximately 100 ml of milk after PEF treatment with Laktodensitometer (Hydroneter – Areometer g/ml. Franq). The milk was placed on beaker glass and density was determined immediately after PEF treatment. *Viscosity* was measured from approximately 200 ml of milk after PEF treatment using rotary viscometer (model LVT, Brookfield Engineering Laboratories, Inc. USA). Milk was placed in beaker glass and viscosity was determined at 30 rpm. *Water Content* of milk was analyzed using

Halogen Moisture Analyzer (HB 43 Mettler Toledo, Switzerland). Approximately 15 ml of milk after PEF treatment was analyzed. The measurement of *Boiling Point* was conducted with boil 1000 ml of milk on the pan equipped with thermometer until reach the boiling point. The boiling point was indicated with the appearances of gas bubbles on the pan. The value of boiling point was shown in thermometer. The measurement of *Freezing Point* was conducted with inserted xx ml milk onto refrigerator for approximately 12 hours. Thermometer was contacted with milk during cooling process. The value of freezing point was shown in thermometer when milk was frozen. The color was measured from approximately 50 ml of milk using color analyzer (PCE-RGB 2 Color Analyzer, PCE Deutschland GmbH) at room temperature. Equipment was set up with 0º of observe angle, providing values of HSL (Hue, Saturation, Lightness).

One liter of raw whole milk were obtained from local dairy farm for processing by selected methods. The PEF treatment was carried out using PEF laboratory unit, set with three levels of treatment voltage (i.e. 60 kV; 80 kV; and 100 kV) and performed in three different treatments duration (i.e. 10 s; 20 s; and 30 s). The effects of nine variants of combinations of PEF treatments were analyzed immediately after process.

Effects of variables of both treatments on density, viscosity, water content, boiling point, freezing point, turbidity level, red level (a+), and yellow level (b+) were investigated. Three replications of each measurement process were conducted. The average value was calculated from each parameters on replications used as representative value of each parameters.

3. RESULTS

Density. Fig. 3 presents the change of milk density data for various treatments averaged over the entire PEF treatments with different levels of treatment voltage i.e. 60 kV; 80 kV; and 100 kV and performed in three different treatments duration i.e. 10 s; 20 s; and 30 s.

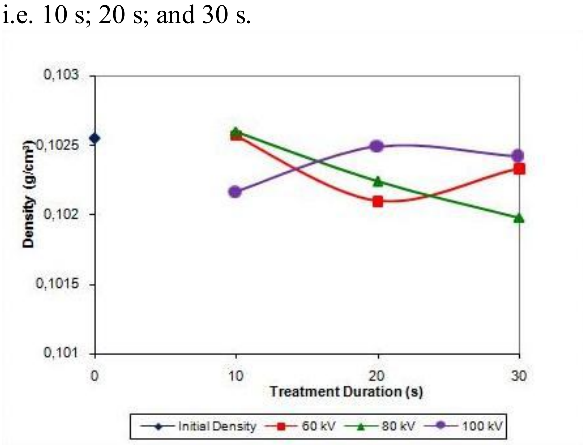


Fig. 3. *The Change of Milk Density for Various Treatments*

The initial density of milk before treatments was 0.10255 g/cm^3. It can be seen from Fig. 3 that the density of milk was highest after 80 kV treatment voltage for 10 s of treatment duration, i.e. 0.10260 g/cm^3; while the density of milk was lowest after 80 kV treatment voltage for 30 s of treatment duration, i.e. 0.10198 g/cm^3.

Viscosity. Fig. 4 shows the change of milk viscosity data for various treatments averaged over the entire PEF treatments with different levels of treatment voltage i.e. 60 kV; 80 kV; and 100 kV and performed in three different treatments duration i.e. 10 s; 20 s; and 30 s.

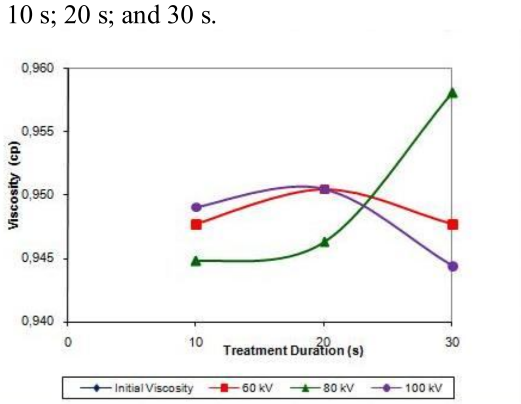


Fig. 4. *The Change of Milk Viscosity for Various Treatments*

The initial viscosity of the milk before treatments was 0.9368 cp. It can be seen form Fig. 4 that the viscosity of milk was highest after 80 kV treatment voltage for 30 s of treatment duration, i.e. 0.9581 cp; while the viscosity of milk was lowest after 100 kV treatment voltage for 30 s of treatment duration, i.e. 0.9444 cp.

Water Content. Fig. 5 demonstrates the change of milk water content data according to various treatments averaged over the entire PEF treatments with different levels of treatment voltage i.e. 60 kV; 80 kV; and 100 kV and performed in three different treatments duration i.e. 10 s; 20 s; and 30 s.

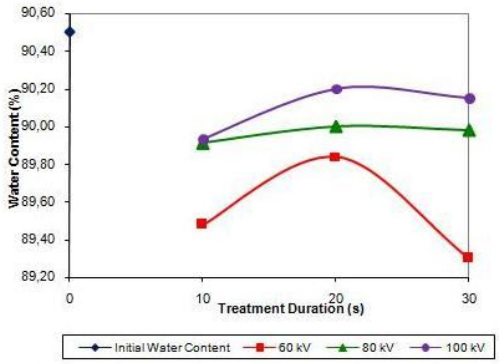


Fig. 5. *The Change of Milk Water Content for Various Treatments*

The initial water content of milk before treatments was 90.50%. It can be referred from Fig. 5 that the highest and lowest water content of milk was found to be 90.20% and 89.48% in case after 100 kV treatment voltage for 20 s of treatment duration and after 60 kV treatment voltage for 10 s of treatment duration, respectively.

Boiling Point. Fig. 6 shows the change of milk boiling point data for various treatments averaged over the entire PEF treatments with different levels of treatment voltage i.e. 60 kV; 80 kV; and 100 kV and performed in three different treatments duration i.e. 10 s; 20 s; and 30 s.

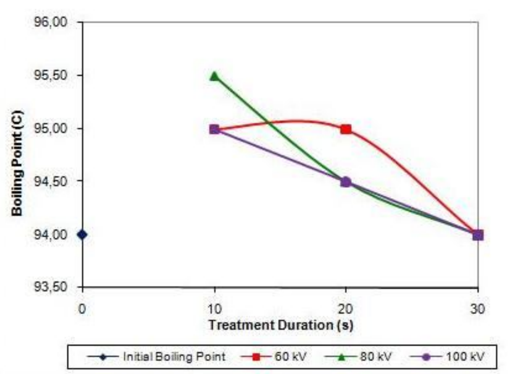


Fig. 6. *The Change of Milk Boiling Point for Various Treatments*

The initial boiling point of milk before treatments was 94ºC. It can be referred from Fig. 6 that the boiling point of milk was highest after 80 kV treatment voltage for 10 s of treatment duration, i.e. 95.5ºC.

Freezing Point. Fig. 7 shows the change of milk freezing point data for various treatments averaged over the entire PEF treatments with different levels of treatment voltage i.e. 60 kV; 80 kV; and 100 kV and performed in three different treatments duration i.e. 10 s; 20 s; and 30 s. The initial freezing point of milk before treatments was -3ºC, while after the treatment was in range of -4 to -5ºC.

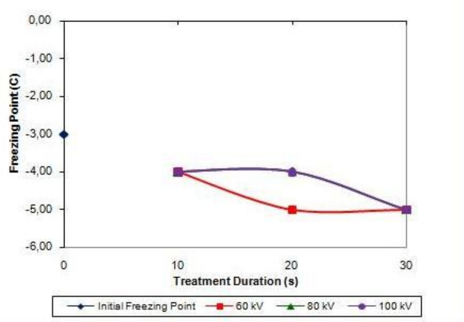


Fig. 7. *The Change of Milk Freezing Point for Various Treatments*

Turbidity Level. Fig. 8 illustrates the change of milk turbidity level data for various treatments averaged over the entire PEF treatments with different levels of treatment voltage i.e. 60 kV; 80 kV; and 100 kV and performed in three different treatments duration i.e. 10 s; 20 s; and 30 s.

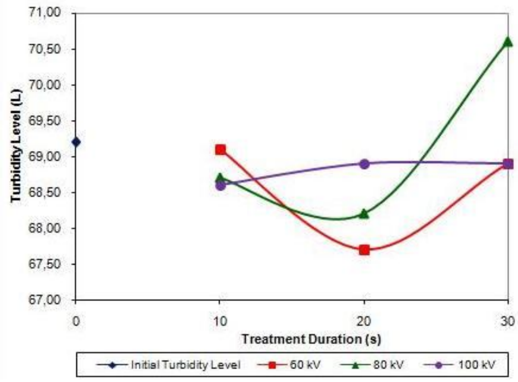


Fig. 8. *The Change of Milk Turbidity Level for Various Treatments*

The initial turbidity level of milk before treatments was 69.20 L. It can be referred from Fig. 8 that the highest and lowest turbidity level of milk was found to be 70.60 L and 67.70 L in case after 80 kV treatment voltage for 30 s of treatment duration and after 60 kV treatment voltage for 20 s of treatment duration, respectively.

Color. Fig. 9 and 10 indicate the change of milk red level (a+) and yellow level (b+) data for various treatments averaged over the entire PEF treatments with different levels of treatment voltage i.e. 60 kV; 80 kV; and 100 kV and performed in three different treatments duration i.e. 10 s; 20 s; and 30 s, respectively.

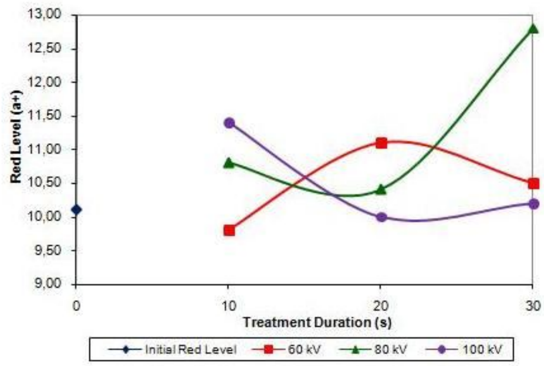


Fig. 9. *The Change of Milk Red Color Level (a+) for Various Treatments*

The initial red color level (a+) of milk before treatments was 10.10. It can be seen from Fig. 9 that the highest and lowest red color level (a+) of milk was found to be 12.8 and 9.8 in case after 80 kV treatment voltage for 30 s of treatment duration and after 60 kV treatment voltage for 10 s of treatment duration, respectively.

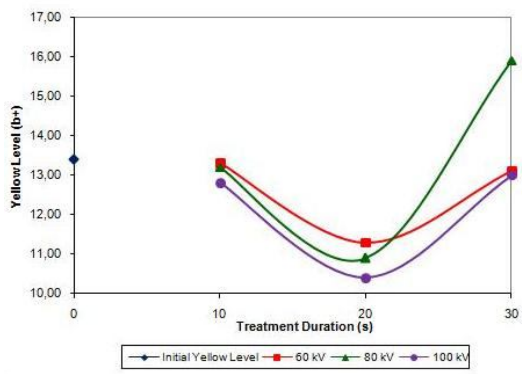


Fig. 10. *The Change of Milk Yellow Color Level (b+) for Various Treatments*

The initial yellow color level (b+) of milk before treatments was 13.40. It can be seen from Fig. 10 that the highest and lowest yellow color level (b+) of milk was found to be 15.90 and 10.40 in case after 80 kV treatment voltage for 30 s of treatment duration and after 100 kV treatment voltage for 20 s of treatment duration, respectively.

4. DISCUSSION

The results indicate that PEF treatment did not significantly change physical properties of milk. The changes that occur were still under normal limit. This condition occurs because during the PEF process, only few temperatures were increased (2-3ºC). According to [14][15], the maximum temperature increases was 5ºC. Therefore, the PEF treatment is good to be applied to the product that has sensitivity to the high temperature, such as milk.

The following aspects was discussed as considerations that PEF treatment did not significantly change the physical properties of milk.

Density. The initial density of milk obtained from this study was 0.10255 g/cm^3 and ranged after PEF treatment from 0.10198 g/cm^3 to 0.10260 g/cm^3. The PEF treatment cause the density of milk tends to decrease. It also can be seen from Fig. 3 that the application of various voltage and treatment time has insignificant impact on density of milk. According to [16], specific gravity varies between 1027-1035 g/cm^3 milk depending on the type and quantity of the dispersed particles. With increasing fat content, specific gravity will decrease. Density will increase when the protein content, lactose and minerals in milk increases. According to [17] gravity could not be degraded by PEF treatment when total dissolved solids, sugar-acid-ratio did not change the amount. This is what underlies the constancy of the density of pasteurization using PEF technology.

Viscosity. The initial viscosity of milk obtained from this study was 0.9368 cp and ranged after PEF treatment from 0.9444 cp to 0.9581 cp. The PEF treatment cause the density of milk tends to increase. It also can be referred from Fig. 4 that the application of various voltage and treatment time has insignificant impact on viscosity of milk. A slight changes in viscosity due to the enzymatic reaction occurs. [18] suggests that the changes in viscosity can be accelerated by enzymatic reactions such as *pectin methylesterase* (PME) and *polygalacturonase* (PG).

Water Content. The initial water content of milk obtained from present study was 90.50% and ranged after PEF treatments from 89.48% to 90.20%. The PEF treatments cause the water content of milk tends to decrease in case compared with initial condition. According to [19], providing high voltage pulses did not take effect on physical properties, especially water content. This condition occurs because the dissolved solid contained in milk is also not change significantly. So that the water contained in milk relatively fixed. [20] also reported that the change in water content of milk could change as well as changes on thermal properties of milk. However, in this study PEF treatment did not changes the temperature of milk significantly. So that PEF treatments also cause insignificant impact on water content of milk.

Boiling Point. In this present study, the initial boiling point of milk was 94ºC and the highest was 95.5ºC after PEF treatments. The PEF treatments cause the boiling point of milk tends to increase in case compared with initial condition, but insignificant (1-2 ºC). It can be inferred that PEF treatments have insignificant impact on boiling point of milk. Variations in milk boiling point occur because there are different types of feed given to animals, seasons, and breeds or types of animals [21]. At the time of the study temperature rises about 2ºC after pasteurization. It is still considered reasonable. According to [14] and [15], the PEF system increase in process temperature is generally a maximum of 5ºC, so this method is very well applied to foodstuffs that are sensitive to high temperatures. Pulsed electric field technology can be used as a method of preserving food without a rise in temperature during the process and to minimize the loss of vitamins, flavor, aroma and color of the product [22]. With PEF pasteurization process referred to as non thermal as processed food ingredients at room temperature or below for several seconds and are able to minimize loss of nutrients caused by heating [6][8].

Freezing Point. The initial freezing point of milk was -3ºC and was in range of -4 to -5ºC after PEF treatment. It can be inferred that the PEF treatment causes a change in heating and freezing, but the change was insignificant than the freezing point of fresh milk. The maximum change occurred at 1ºC. Variations in milk freezing point also occur because there are different types of feed given to animals, seasons, and breeds or types of animals [21]. At the time of the study temperature changes about 2ºC after pasteurization. It is still considered reasonable. According to [14] and [15], the PEF system increase in process temperature is generally a maximum of 5ºC, so this method is very well applied to foodstuffs that are sensitive to high temperatures. Pulsed electric field technology can be used as a method of preserving food without a rise in temperature during the process and to minimize the loss of vitamins, flavor, aroma and color of the product [22]. With PEF pasteurization process referred to as non thermal as processed food ingredients at room temperature or below for several seconds and are able to minimize loss of nutrients caused by heating [8][15].

Turbidity Level. The initial turbidity of milk was 69.20 L and ranged after PEF treatment to be 67.70 L to 70.60 L. This condition reveals that PEF treatment has insignificant effect on physical properties such as turbidity. [23] also reported that preservation of liquid food with PEF treatment in any electric field strengths and total treatment times caused no considerable changes on physical–chemical properties on food.

Color. The color of milk was determined as effect of PEF treatment at various field strengths and total treatment times also caused no considerable changes on color. [24] argues that the color appearance of the products processed with PEF technique is better than the usual thermal techniques. [23] also reported that preservation of liquid food with PEF treatment in any electric field strengths and total treatment times caused no considerable changes on physical–chemical properties on food.

As the recape, the results also indicate that applied higher voltage and treatment duration has insignificant impact on density, viscosity and water content. According to [7][6], a high voltage intensity treatment may inactivate microorganism without causing any negative effect on physical properties and nutrition of the processed food.

The boiling and freezing point, turbidity level, red color level (a+) and yellow color level (b+) of the pasteurized milk by PEF treatment did not change significantly. [25] reported that in the application of PEF treatment to the fruit juice that was stored under 8.5 and 12ºC did not change turbidity (L), red color level (a+) and yellow color level (b+) of the orange-carrot juice. [1] also stated that the appearance of the PEF product is better than products with thermal treatment.

5. CONCLUSIONS

The following major conclusions can be drawn from the present study:

- The PEF treatment has insignificant effect on physical properties of milk, i.e. density, viscosity, water content, boiling point, freezing point, turbidity level and color. Therefore, the PEF treatment is good to be applied to the product that has sensitivity to the high temperature, such as milk.
- The increase in treatment voltage not signicantly change the physical properties of milk, i.e. density, viscosity, water content, boiling point, freezing point, turbidity level and color. The changes on physical properties that occur still under normal limit.
- The increase in treatment duration not signicantly change the physical properties of milk, i.e. density, viscosity, water content, boiling point, freezing point, turbidity level and color. The changes on physical properties that occur still under normal limit.

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