



Analysis of heat loss in wall insulators and sterilizer door covers in palm oil processing factories

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ABSTRACT

The main stage of crude palm oil (CPO) production takes place in the boiling process, which involves the role of sterilizer equipment. One of the ideal standards for producing CPO is to have an oil yield value in the range of 22.5-23.5%. However, the palm oil processing industry only found an oil yield of 20.25%. The decrease in yield was due to the steam pressure entering the sterilizer not being up to standard. Therefore, the purpose of this study is to analyze the effect of steam exiting the sterilizer or heat loss with the help of mathematical equations (including the Nusselt number and Rayleigh number) by utilizing field data. This research in the palm oil processing industry gave the highest result for heat loss at peak III of 58,074 kJ with Bunches of Fresh Fruit (BFF) boiling conditions at 2.7 bar and 130°C and a process time of 600 seconds. The resulting CPO oil yield was 20.25% (a decrease of about 10-14% from the production standard). The industry, together with a third party (a maintenance consultant from outside the company), assessed the need to maintain a continuous production process and a decrease in oil yield (2.25-3.25%). The yield gap leads to solving the problem through an operating condition optimization approach. The treatment that can be applied is equipment extension through the installation of double-glazed windows on the sterilizer equipment to minimize heat loss. This consideration is the best option considering the continuous palm oil production process and is able to prevent partial or total shut-down activities.

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1. INTRODUCTION

Palm oil is a plantation commodity that has a strategic role in Indonesia's economic development. In 2018, palm oil and palm kernel production was recorded at 48.68 million tons, consisting of 40.57 million tons of crude palm oil (CPO) and 8.11 million tons of palm kernel oil (PKO) [1]. CPO is the result of the processing of palm oil from Bunches of Fresh Fruit (BFF), and PKO is oil derived from oil palm fruit seeds (kernels) [2], [3]. One of the companies in Indonesia that processes palm fruit (Bunches of Fresh Fruit, or BFF) into CPO and palm kernel (kernel) is the palm oil processing industry in Banten, with a processing capacity of 60 tons of BFF or "Tandan Buah Segar - TBS". O'clock. Crude palm oil produced from BFF processing is the main raw material for making cooking oil [4]. Therefore, palm oil companies need to pay attention to the production process to produce quality CPO.

The most important process in making CPO is the boiling process in a sterilizer. The purpose of boiling is to soften the palm fruit so that the fiber and seeds are easily separated from the bunch [5].

A cylindrical pressurized steam vessel (sterilizer) functions to boil BFF with a heating medium, namely steam originating from the back pressure vessel (BPV) [6]. BPV is a tank that functions as a reservoir for steam generated by the turbine [7]. This palm oil processing factory uses a triple peak system consisting of single, double, and triple peaks in the boiling process. During the single peak process, steam from the BPV enters the sterilizer until the pressure reaches 1.5 bar. Meanwhile, the steam entering the double peak process reaches a pressure of 2.5 and 2.7 bar for the triple peak process. If the three-peak system is fulfilled, then the BFF boiling process can begin. This boiling lasts for 115 minutes at a pressure of 2.7 bar and a temperature of 130°C. The purpose of the triple peak process is to transfer steam to the inside of the BFF.

Making CPO depends on the boiling process because it can determine the quality of the final product [8]. Success in the boiling process will support ease in the next process, namely the thrashing, pressing, digester, and clarification stations [9]. The problem with palm oil companies is the yield resulting from the boiling process. The palm oil industry in Banten states that the product has met the requirements if the amount of CPO yield is 22.5-23.5% [10]. However, the resulting yield is sometimes below the predetermined requirements. Several factors that can influence the amount of CPO yield are pressure, temperature, boiling time, and steam from BPV [11]. Usually, low CPO yields are caused by BFF, which is not fully cooked during the boiling process in the sterilizer [12]. This can be seen from the steam that comes out through the walls and door of the sterilizer because the insulators that function to maintain heat, such as rockwool and aluminum, are running low. An insulator is a heat transfer material that has a certain thermal conductivity value and aims to maintain the heat that occurs inside the sterilizer [13]. Based on problems in this industry, the research aims to determine the steam that comes out of the sterilizer walls and doors using heat transfer calculations (heat loss).

2. RESEARCH METHOD

2.1. Field Data

The data collected for this research is in the form of primary and secondary data from palm oil processing factories in the Banten area, which are presented in Figure 1, and Tables 1-2. Both data were obtained by involving direct observation (observation for one month) as well as research support from relevant references, respectively, in analyzing heat loss on the walls and closing the sterilizer door [14].

Table 1. Data on palm oil processing and sterilization equipment units

Sterilizer				Lorry	
Type	Horizontal	Pressure (bar)		Material	Iron plate
Cylinder length (L_S , m)	3.1	Maximum	3.5	Length (L, m)	2.5
Outside diameter (D_{LS} , m)	2.1	Steam peak I	1.5	Height (m)	1.5
Thickness (m)		Steam peak II	2	Width (m)	2.1
Inner wall	0.015	Steam peak III	2.7	Radius (r, m)	2
Rockwool	0.05	Temperature (°C)		Initial temperature (°C)	28
Alumunium	0.001	Steam peak I	100		
Thermal conductivity (k, W/m.K)		Steam peak II	120		
ASTM-A36-SS400 (k_1)	50	Steam peak III	130		
Rockwool (k_2)	0.0415	Surrounding air	28		
Alumunium (k_3)	237	Condensate mass (kg)			
Radius of wall layer (m)		Peak I	54.72		
r_1	2.034	Peak II	91.54		
r_2	2.049	Peak III	112.12		
r_3	2.009				
r_4	2.1				
Door diameter (D_{PS} , m)	2.26				
Door radius (m)					
r_1	1.13				
r_2	1.19				

Table 2. Data on gas properties at atmospheric pressure

Film Temperature (T_f , K)	k (W/m.K) $\times 10^{-2}$		α (m^2/s), $\times 10^{-5}$		μ (m^2/s), $\times 10^{-5}$		Pr	
	Air	Steam	Air	Steam	Air	Steam	Air	Steam
337 at peak I	2.9038	2.1375	2.7976	1.395	1.96122	1.61545	0.70182	1.103
347 at peak II	2.9778	2.2125	2.9456	1.545	2.06182	1.74395	0.70042	1.093
347 at peak III	3.0152	2.2500	3.0236	1.620	2.11396	1.80820	0.69960	1.088

Note: k , α , μ , and Pr are thermal conductivity, thermal diffusivity, kinematic viscosity, and Prandtl number, respectively.

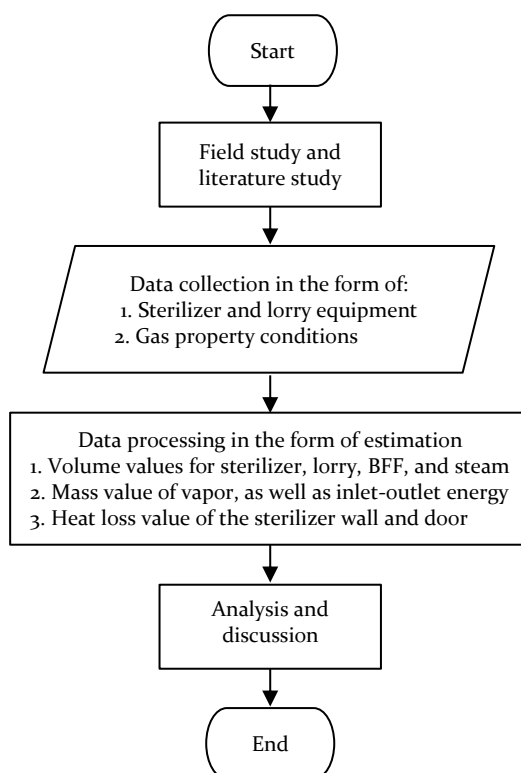


Figure 1. Research flow diagram for palm oil industry in Banten area

2.2. Data processing

Utilization of mathematical equations (1) to (13) helps in processing field data to support Figure 1, and Tables 1-2 before.

$$\text{Sterilizer volume} \quad V_S = \frac{1}{4} \pi \times D_{LS}^2 \times L_S \quad (1)$$

$$\text{Lorry volume} \quad V_{\text{lorry}} = A_{\text{lorry}} \times L_{\text{lorry}} \quad (2)$$

$$V_{\text{lorry}} = (\text{height} \times \text{width})_{\text{lorry}} \times L_{\text{lorry}}$$

$$\text{TBS volume} \quad V_{\text{TBS}} = \pi \times (r^2 \cdot L)_{\text{lorry}} \quad (3)$$

$$\text{Steam volume, } m^3 \quad V_{\text{steam}} = V_S - V_{\text{lorry}} - V_{\text{TBS}} \quad (4)$$

From the condition of the sterilizer volume size to the steam volume, the need for energy supplied in the form of steam is a continuation of the condensation process for peaks I, II, and III [14], [15].

$$\text{Steam mass} \quad m_{\text{steam}} = \rho_{\text{steam}} \times V_{\text{steam}} \quad (5)$$

Energy in $E_{in} = m_{steam} \times h_{steam}$ (6)

Energy out $E_{out} = m_{condensate} \times h_{condensate}$ (7)

Heat transfer occurs due to temperature differences. Providing steam from the BPV flows to the sterilizer at high to low temperatures. Heat transfer can occur through conduction and convection [16]. Conduction takes place from one body to another through physical contact. Convection occurs if the surface and fluid flow through the boundary layer or layer [17]. The sterilizer wall in the palm oil processing industry is in the form of a cylindrical pressure vessel [18]. Then, the door is a cylindrical sphere [19]. The sterilizer door is expressed as the thermal resistance of the sphere layer to heat conduction.

Heat loss of sterilizer walls

$$Q_{loss} = \frac{\Delta T}{R_{total}} = \frac{T_{steam} - T_{air}}{R_{total}}$$

($R_{total} = R_{conduction} + R_{convection}$)sterilizer wall

$$R_{conduction} = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k_1 L_S} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{2\pi k_2 L_S} + \frac{\ln\left(\frac{r_4}{r_3}\right)}{2\pi k_3 L_S} + \dots$$
 (8)
$$R_{convection} = \frac{1}{(2\pi r_1 L_S \times h_{steam})} + \frac{1}{(2\pi r_2 L_S \times h_{air})}$$

Heat loss of sterilizer door

$$Q_{loss} = \frac{\Delta T}{R_{total}} = \frac{T_{steam} - T_{air}}{R_{total}}$$
 (9)
$$R_{total} = \frac{1}{(4\pi r_1^2 h_1)} + \frac{r_2 - r_1}{4\pi k_1 r_1 r_2} + \frac{1}{(2\pi r_2^2 h_2)}$$

Note: h_1 and h_2 are convection coefficient values for steam and air, respectively, and R is thermal resistance.

Equations (8 and 9) require the value of the convection coefficient for both air and steam. The heat transfer coefficient cannot be measured, but an approach can be used in the form of:

$$h_i = \frac{Nu_D \times k_i}{D}$$
 (10)

$$D = D_{LS}/D_{PS}$$

where: h_i can be the convection coefficient of air or steam; Nu_D is the Nusselt number; and k_i refers to property data for steam or air in Table 2.

The Nusselt number will be obtained from Equation (11-12) for the sterilizer walls and doors.

Cylindrical pressure vessel

$$Nu_D = \left\{ \begin{array}{l} 0.60 + \frac{0.387 Ra_D^{\frac{1}{4}}}{\left[1 + \left(\frac{0.559}{Pr} \right)^{\frac{9}{16}} \right]^{\frac{8}{27}}} \end{array} \right\}^2 Ra_D \lesssim 10^{12}$$
 (11)

Sphere cylindrical layer

$$Nu_D = \left\{ 2 + \frac{0.387 Ra_D^{\frac{1}{4}}}{\left[1 + \left(\frac{0.469}{Pr} \right)^{\frac{9}{16}} \right]^{\frac{4}{9}}} \right\} Pr \geq 0.7 Ra_D \tag{12}$$

Rayleigh number

$$Ra_D(i) = \frac{g \times \beta (T_{steam} - T_{air})D^3}{\alpha \times \mu} \tag{13}$$

$$\beta (i) = \frac{1}{T_f}$$

$$\frac{1}{T_f} = \frac{T_{steam(i)} + T_{air}}{2}$$

Note: $g = 9,81 \text{ m/s}^2$ – Earth's gravitational force; convection coefficient values for steam and air, respectively

3. RESULTS AND DISCUSSIONS

Utilizing mathematical equations (1) to (4) gives results in the form of volumes for the sterilizer, lorry, BFF, and steam. The quantity is 107.317; 7.85; 7.85; and 91.592 m³, respectively. A summary of other results is presented in Table 3 and Figures 2–3.

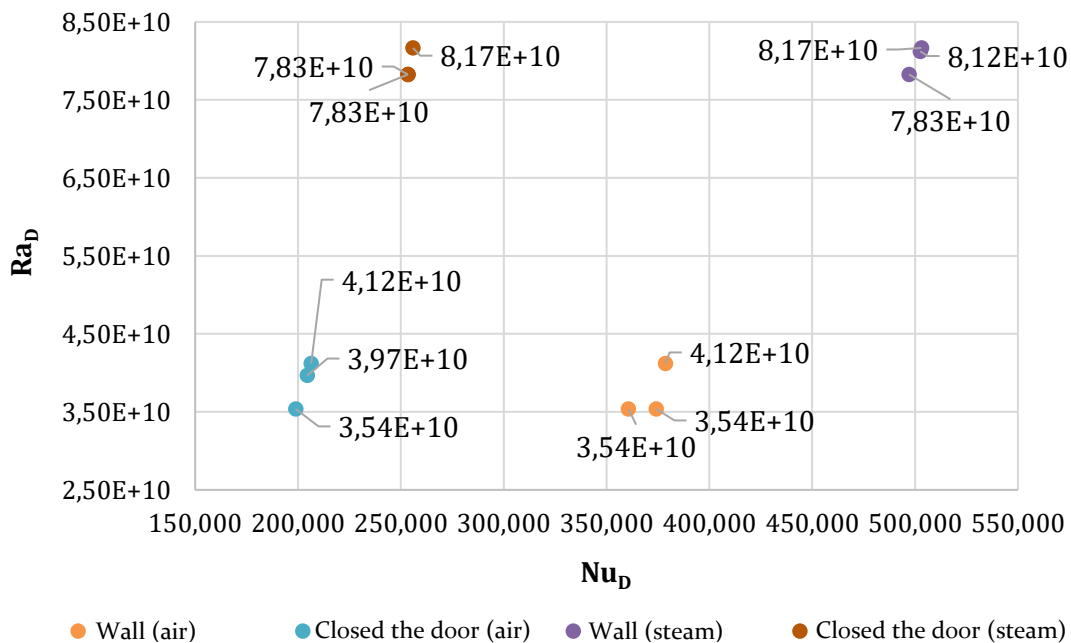


Figure 2. Relationship between Rayleigh and Nusselt numbers on sterilizer walls and doors

Table 3. Estimated heat loss from the wall insulator and sterilizer door cover

Area	P and T (bar; °C)	E _{in} (kJ)	E _{out} (kJ)	Q _{loss of wall} (kJ)	Q _{loss of door} (kJ)	Boiling time (s)
Peak I	1.5; 100	149,025.2	146,408.8	4.797	27.920	480
Peak II	2; 120	279,552.9	244,924.4	6.81	35.690	480
Peak III	2.7; 130	372,964.5	299,988.3	8.595	49.480	600

Table 3 and Figure 2 provide calculation results showing that the Rayleigh number indicates the level of buoyancy force, which can result in large fluid turbulence effects so that the flow of air mixing at the surface is also greater. The Nusselt number is a dimensionless parameter to indicate the amount of heat transfer [20]. Increasing the Rayleigh number gives a straight ratio to the Nusselt number, which is also increasing. The temperature and pressure entering the sterilizer also affect both numbers. This is in accordance with research conducted by [21], [22], which states that the average convection Nusselt number is a function of the Rayleigh number. The application of equations (10) to (13) is presented in Figure 3. Then, the two numbers are one of the parameters for determining the value of the convection coefficient for both air and steam.

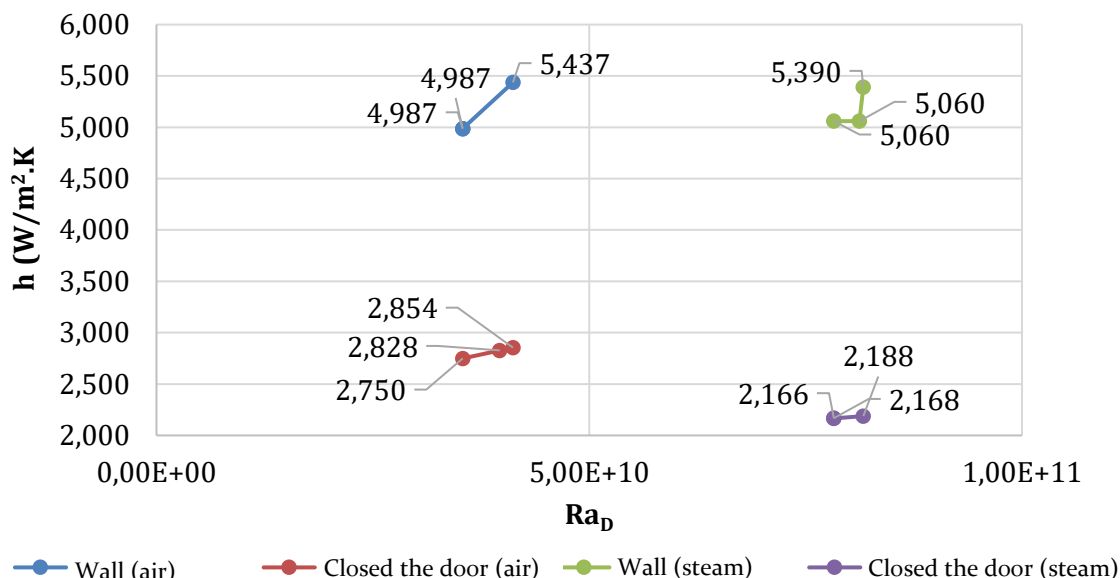


Figure 3. The relationship between the air and steam convection coefficients and the Rayleigh number on the sterilizer walls and doors

Figure 3 for peaks I-III shows an increase in the convection coefficient on both the walls and the sterilizer door cover. The overall results of the air and steam convection coefficient values have increased due to the influence of the Rayleigh number, Nusselt number, pressure, and temperature. The magnitude of both numbers has an impact on greater convection heat transfer. The value of the air and steam convection coefficients on the wall can also influence the thermal resistance value (R) both by conduction and convection. The cylindrical shape of the sterilizer wall is able to accommodate larger convection coefficient values. This shows that the walls and door closers have various convection heat transfer characteristics. This assumption is supported by the statement that the shape of the cross section can influence the temperature inside the vessel so that the heat transfer rate by convection will increase or decrease [23].

The boiling time presented in Table 3 in relation to the quantity of heat lost is an important aspect of the energy and operational management of the sterilizer equipment unit. This presentation shows that the peak I to peak III areas have an increasing quantity of heat lost as time increases. This

was previously supported by an increase in the Rayleigh and Nusselt numbers as well as the convection coefficient values for both air and steam.

Thinning the insulator on the walls and closing the sterilizer door can cause large heat losses. This is because the amount of steam that enters can escape through the gaps in the isolator, and ultimately, during the process of boiling the palm oil in the sterilizer unit, it is not perfect. This impact resulted in a low-value CPO yield of around 20.25% (generally, the industry gets 22.5–23.5%). The suspicion of heat loss is supported by cracks in the sterilizer. This damage can cause imperfections in cooking BFF because the heat that enters the sterilizer can escape through cracks and reduce the CPO yield value targeted by the industry [24].

The thickness of the sterilizer insulator plays a role in minimizing the heat that escapes. If the insulator has the maximum thickness, less heat loss will occur. Then, operational factors can also influence the energy level in the sterilizer, such as temperature, boiling time, and pressure. According to other studies, the right pressure and time characteristics can also reduce CPO oil loss [25]. Applications can be made to reduce heat loss, namely carrying out evaluations of the materials used in the construction of the sterilizer and regular maintenance schedules for the condition of the sterilizer to prevent undetected heat leaks. Another important thing is setting the pressure and operating time of the sterilizer according to the procedures applied by the industry. Optimal application of these two operating conditions can help maintain a stable process temperature and avoid excessive fluctuations during sterilizer operation [26], [27].

Good sterilizer maintenance will help maintain the performance of the isolator and optimize the efficiency of the process energy supply. Another option could be implementing a thermal insulation system in the form of double-glazed windows. This action is a very effective solution for reducing heat loss [28]. In line with [29], the installation of double-glazed windows can reduce heat loss out of the window.

4. CONCLUSION

Based on the results of research that has been carried out, it is known that the highest quantity of heat lost during the BFF boiling process in the sterilizer equipment unit is in the peak III area, amounting to 58.074 kJ (2.7 bar and 130°C) which should be at 3 bars for ideal conditions. The process conditions are caused by the Rayleigh and Nusselt numbers; the convection coefficient of both air and steam and the thermal resistance of conduction-convection have increased in value. Then, the insulator segment also influences the heat lost, namely the thinning of the rockwool and aluminum sections. The closest preventive measure that can be proposed to the palm oil processing industry is to implement the use of a thermal insulation system, one of the options being double-glazed windows. This technology is categorized as very effective in reducing the amount of heat lost. Operational factors are also applied by referring back to the company's standard operational procedure, especially pressure, temperature, and BFF boiling time, on the yield of CPO produced. These three process conditions are also able to contribute to energy stability in the sterilizer unit by suppressing excessive energy fluctuations. The recommendation for further research is to focus on the use of double-glazed windows and cost breakdown through the application of relevant methods. The prevention of partial or total shut-down activities and the handling of damage with or without extending process equipment are also economical concepts to be considered by third parties in carrying out regular maintenance activities.

NOTATIONS

A_{lorry}	: area lorry	m^2
D	: outside diameter	m
D_{LS}	: sterilizer's outside diameter	m
D_{PS}	: sterilizer's door diameter	m
E_{in}	: energy in	kJ
E_{out}	: energy out	kJ
g	: Earth's gravitational force	m/s^2
h_1	: convection coefficient value for steam	$\text{W/m}^2.\text{K}$

h_2	: convection coefficient value for air	$W/m^2.K$
$h_{\text{condensate}}$: condensate enthalpy	kJ/kg
h_i	: heat transfer coefficient	$W/m^2.K$
H_{lorry}	: lorry height	m
h_{air}	: steam convection coefficient	$W/m^2.K$
h_{steam}	: steam enthalpy	$W/m^2.K$
k	: thermal conductivity	kJ/kg
k_1	: 1 st thermal conductivity	
k_2	: 2 nd thermal conductivity	
k_3	: 3 rd thermal conductivity	
L_S	: sterilizer's cylinder length	m
L_{lorry}	: lorry's length	m
$m_{\text{condensate}}$: condensate mass	kg
m_{steam}	: steam mass	kg
Nu_D	: the Nusselt number	-
Pr	: the Prandtl number	-
Q_{loss}	: heat loss	kJ
$r_{n \text{ sterilizer}}$: door radius in sterilizer, with $n = 1$, and 2	m
r_1	: 1 st door radius	
r_2	: 2 nd door radius	
$r_{n \text{ sterilizer}}$: radius of wall layer in sterilizer, with $n = 1, 2, 3$, and 4	m
r_1	: radius of the 1 st wall layer	
r_2	: radius of the 2 nd wall layer	
r_3	: radius of the 3 rd wall layer	
r_4	: radius of the 4 th wall layer	
r_{lorry}	: lorry radius	m
$R_{\text{conduction}}$: conduction thermal resistance	K/W
$R_{\text{convection}}$: convection thermal resistance	K/W
R_{total}	: thermal resistance total	K/W
Ra_D	: the Rayleigh number	-
T_{air}	: air temperature	K
T_f	: film temperature	K
T_{steam}	: steam temperature	K
V_{lorry}	: lorry volume	m^3
V_S	: sterilizer volume	m^3
V_{steam}	: steam volume	m^3
V_{TBS}	: TBS volume (Tandan Buah Segar or Bunches of Fresh Fruit - BFF)	m^3
W_{lorry}	: lorry width	m
ΔT	: temperature difference	-
α	: thermal diffusivity	m^2/s
μ	: kinematic viscosity	m^2/s
ρ_{steam}	: steam density	kg/m^3
β	: coefficient of thermal expansion	$1/T_f$

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