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Study of heating and cooling temperature of injection molding to effect on gloss of plastic injection parts

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Abstract. Injection molding process is one of the most extensively used for manufacturing plastic processes due to high productivity, high efficiency and also the manufacturing of the net shape or complex design parts. In general, the finished plastic parts are a growing trend towards using in automotive part, electronic appliance and require more direct appearance surfaces. Nowadays, plastic injection parts do not need to be painted or coated for the manufacturing processes and weld marks on the surface parts must be completely eliminated. The objective of this study is to focus on the effect of gloss in plastic part using ABS (Acrylonitrile Butadiene Styrene) materials and design of experiment by using Response Surface Methodology (RSM) to independent temperature variables. This research represents the optimize efficiency of the thermal factor in molding effect to gloss parameter on plastic injection parts and provides the estimate of the parameter related to high-temperature behavior in molding before injection process. The result of experiments have been obtained the measuring point of cavity temperature at 70 ºC, the injection temperature at 240 ºC, and injection speed 120 mm/sec on the 95% confidence interval.

1. Introduction

At the present, plastics manufacturing by using injection molding machines have been used in widespread. Especially, the production of plastic parts such as automotive parts or electronic component parts etc [1]. The parts have been designed the accuracy of control processes shows a surface appearance and color tones, which are the focus on value-added and manufacture reduction. To improve mold ability and physical properties of the plastic material have used in various injection molding processes directly. By the way, the main manufacturing process can be reduced or replaced by previous processes from a good design earlier. Workpieces or parts does not have the effect on other influence in the painting and assembly processes. As more indirect benefits result will not invest about new booth paint and reduce lead time, which in many methods in order to protect inherent defects on final products to anti-scratch proof and eliminate waste.

The injection molding processes include filling, packing, cooling and ejecting processes, generally, cooling stage takes up more than half of cycle time. Therefore, mold temperature has a significant effect on a molding cycle and productivity, but low mold temperature may be melted a plastics not well, and do not fulfill in impression and usually means lower quality in conventional injection molding (CIM) process. In the CIM, mold temperature is kept at constant during cycle time although in the fact it fluctuates in the relatively small range of temperature due to the quality of injection parts.

In manufacturing commonly used the continuous cooling method by circulating coolant in cooling channel, in order to target better quality and high productivity, mold temperature must be lower than the transition temperature of plastic material [2-3].

In real manufacturing, plastic injection mold mostly uses the simulation to predict the finished injection parts. Finite element method (FEM) has been applied the analysis of injection processes in order to reduce the machine setting time [4-5]. Shih-Chih, Ni et al. [6] have proposed the control of bending of the plastic injection parts. The principle of mold temperature based on experimental design. For this reason, a new technology in injection molding has been required to commercial. Rapid heat cycle molding (RHCM) technology has developed and attached in the near future. The difference between CIM and RHCM processes is mold temperature control ability. The constant temperature was controlled in each injection cycle by heating and cooling, which has been applied in the last century. In RHCM process, the cavity mold temperature heated up higher than thermal deflection temperature of plastic about 10 °C before melt plastic filling, and then cooling mold down quickly when packing stage is completed to eject parts. Higher temperature molding situation, frozen layer in RHCM process gives the result to melt flow resistance can be reduced, but CIM process that frozen layer can be completely eliminated. From this reason, injection pressure and clamping force parameter required of injection machine are decreased. On other properties of melt plastic when filling stage can be reduced weld line on part surface significantly by increase mold temperature. Meanwhile, several types of research in a literature using RHCM molding process demonstrates rapid heating and take more effectively lengthen the melt flow path [7-8], improve the part surface appearance in automotive and electronic component parts [9].

In RHCM process benefits on increasing productivity and shorten cycle time are necessary. The heating method mainly uses in industries to achieve this purpose include induction heating, infrared heating, gas-assisted heating and convection heating using hot fluids such as oil, water or steam [10-11]. However, the parameter not yet clear about appropriate parameter to predict the deflection problem. Sivaraos et al. [12] have proposed to a comparison about experimental design between Taguchi method and Respond surface methodology (RSM), the results show RSM are more clearly predicted and significant of all combinations of interactions and squared terms.

A corresponding RHCM process designed and constructed by FEM analyses and experiment to evaluate thermal stress analysis also performed to evaluate thermal stress distribution in cavity molding proposed to alleviate the thermal stress. Finally, the surface appearance quality of plastic part on RHCM process was improved gloss surface compared with more benefits directly. Therefore, the objective of the present research is to propose the optimize efficiency of the thermal factor in molding effect to gloss parameter on plastic injection parts.

2. Mold Structure and Principle of Heating Technology

2.1 Mold and parameter design

Figure 1 illustrates the typical molding structure for developed heating technology with the hot oil convection heating method. The heating channel is installed in cavity plate due to injection parts appearance shown on this side only when the temperatures of the cavity side are elevated to preset mold temperature controller unit will turn off to stop heating, and then the mold is closed for melt plastic filling. Finishing injection part as shown in figure 2.

The plastic material used for the parts is acrylonitrile butadiene styrene (ABS) typed resin Toyolac grade 700 - 314 supplied from Toray Plastics. It has the density of 1.04 g/cm^3 and mass flow rate of 23 g/10min. Before injection processes dying ABS material of 80°C for 4 hours and feed to the barrel. The recommended processing parameter setting in table 1. All parameters carried on injection molding machine using Toshiba Machine model EC100S with I2A Barrel type, this model specification on maximum clamping force 100 tons.

Table 1. Processing parameter in injection experimental.

Processing parameter	Typical value
Injection temperature (°C)	200 - 240
Mold temperature (°C)	50 - 90
Injection speed (mm/sec)	100 - 140
Ejection temperature (°C)	95
Injection filling time (sec)	0.5
Packing time (sec)	3.5
Injection pressure (Mpa)	140
Cooling time (sec)	30 - 45

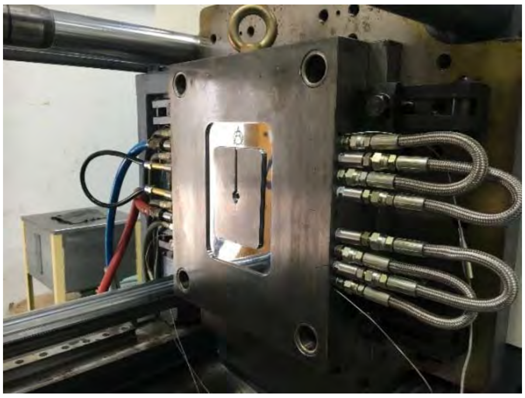

Figure 1. Injection molding design with the hot oil heating.

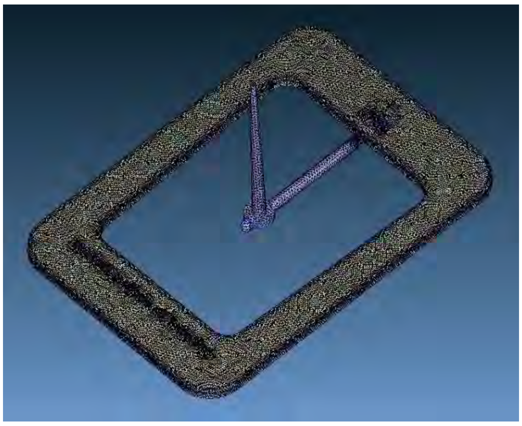

Figure 2. Structure of plastic injection part.

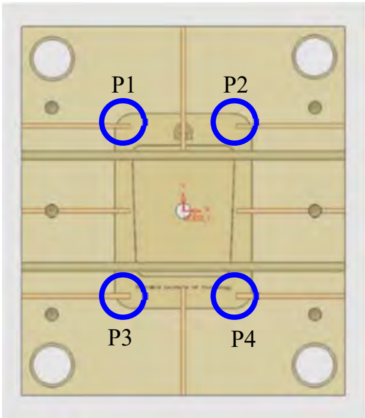

Figure 3. Thermocouples channel design on cavity molding.

2.2 Thermal response and gloss measurement design

As shown in figure 3 identifiers 'P1', 'P2', 'P3' and 'P4' are four positions on cavity side for measuring temperature responses. Using thermocouples type J in research due to the short range of temperature measuring and well responsibility. The used material of cavity plate is a type of plastic mold steel, typed S50C, supplied by Taikin standard mold base Co., Ltd., Thailand.

Point measurement of gloss on injection parts was set to close corners of injection parts, totals 4 point same thermocouples measurement points. Cause of this research focuses on thermal design effect on plastic injection parts. In value added product surface research gloss appearance on the surface measured by gloss unit (GU) with gloss level measurement method. It is also compatible with the standard ASTM D523 using a portable gloss-meter model NHG268 supplies from Shenzhen 3nh technology Co., Ltd., China. The planning of DOE and data analysis was carried out using the statistical software package of Minitab 17.

2.3 Design of experiments (DOE)

The method of defining and investigating all conditions in experiments involving multiple factors in known as Design of experiments (DOE). According to DOE are widely used in many factors examples Full-factorial design, Taguchi method and Response surface methodology to performing an experiment, varying the levels of all factors simultaneously rather than one, allows for interactions between the factors.

2.3.1. Response surface methodology (RSM)

Response surface methodology can be described as s technique on complex calculation processes. To approach a suitable experimental design that integrated all of the independent variables and set equations on the theoretical value of an output [13]. In RSM can predict response result by the regression equation. First order use for linear surface and second order use nonlinear or curved surface, shown as in equation (1) and (2) respectively.

$$\hat{y} = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \varepsilon \quad (1)$$

$$\hat{y} = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k}\sum_{j=1}^{k} \beta_{ij} x_i x_j + \varepsilon \quad (2)$$

2.3.2 Central Composite Design (CCD)

Response surface methodology comprised of several methods to design the experimental procedures and one of them is Central Composite Design (CCD). Optimization carried out with CCD can allow screening of a broad range of parameters as well as the role of each factor [14]. In addition, CCD is also able to evaluate a single variable or the cumulative effect of the variables on the response. Although this ability is shared with the other types of experimental design such as full factorial and partial factorial method, it differs in a way that the experimental runs are reduced.

In figure 4 shows CCD components including factorial points, Axis points and center point using 3 variables factor mold cavity temperature (MT), injection temperature (HEN) and injection speed (VI). The combination with center point 5 points, which used totals all of 19 experiments. The researcher using 3 factors on rotatable design choose α = 1.68 and $-\alpha$ = -1.68 for axis points

Table 2 shows experimental design and levels design on chosen parameter 3 factors and 5 levels on CCD. Each experiment produced injection parts total 5 pieces and before next experiment ejects plastic parts 10 shots for equilibrium thermal system and condition in molding frequently.

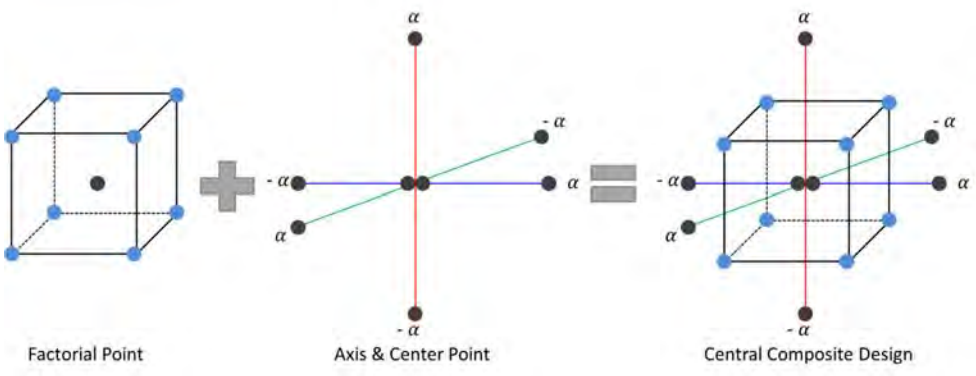

Figure 4. Central Composite Design (CCD) design for three factors.

Table 2. Experimental design parameters and levels.

Parameter	Code	Level				
		$-\alpha$	-1	0	1	α
Cavity temperature (°C)	MT	53.2	60	70	80	86.8
Injection temperature (°C)	HEN	203.2	210	220	230	236.8
Injection speed (mm/sec)	VI	103.2	110	120	130	136.8

3. Experimental Evaluation of Thermal Response

3.1 Experimental analysis data

Using design DOE by surface response method, the influence of independent variables was investigated. And in combination with CCD measure at point P1-P4 by gloss-meter with ASTM D523 standard on measurement angle 60°, using statistic model for calculating average data 3 times per measurement point. The result of gloss unit of the experiment as shown in Table 3.

Table 3. Experimental result using Central Composite Design for three factors.

Central Composite design	Run/Trail No.	Cavity temperature (°C)	Injection temperature (°C)	Injection speed (mm/sec)	Gloss Unit (GU)
Factorial point	1	60	210	110	85.26
	2	80	210	110	89.11
	3	60	230	110	91.68
	4	80	230	110	90.24
	5	60	210	130	83.55
	6	80	210	130	89.62
	7	60	230	130	92.74
	8	80	230	130	91.85
Axis point	9	53.2	220	120	89.05
	10	86.8	220	120	90.80
	11	70	203.2	120	85.58
	12	70	236.8	120	93.29
	13	70	220	103.2	88.07
	14	70	220	136.8	91.08
Center point	15	70	220	120	90.62
	16	70	220	120	92.02
	17	70	220	120	91.94
	18	70	220	120	92.07
	19	70	220	120	91.75

3.2 Data analysis

The statistical software package "Minitab 17" was used to analyze data results obtained from the experiments. Using 95% confidence interval (α = 0.05), A normal probability plot shown in figure 5 is used to relative magnitude and statistical significance. In the figure, points do not fall close to straight line (red point) usually signal factors with the significant effects. And figure 6 shown Pareto chart confirm the result displayed in figure 5 all of three factors have passed the reference line at 2.26 and factor of injection temperature (HEN) having the largest effect on gloss surface. On remaining parameter mold cavity temperature (MT) and injection speed (VI) was followed effects by respectively.

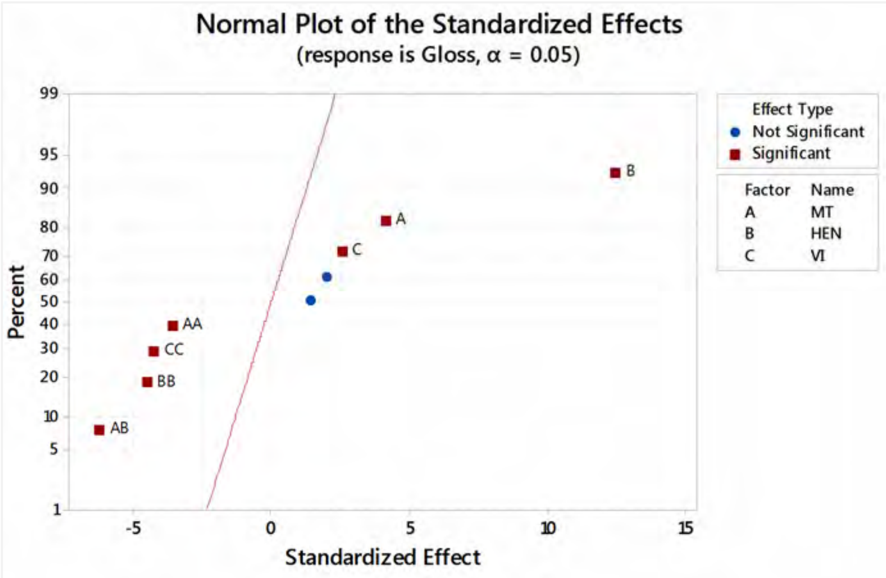

Figure 5. Normal probability plot response

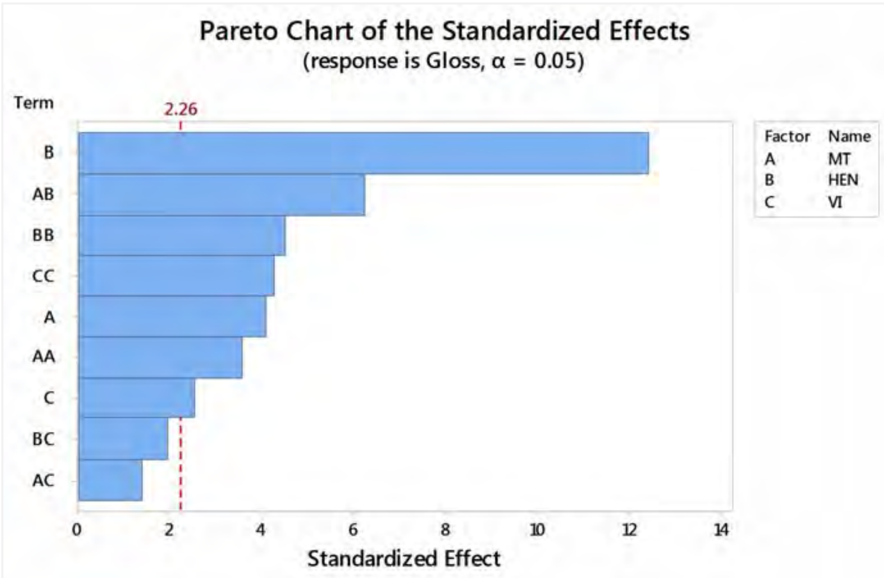

Figure 6. Pareto chart response on gloss unit

From Table 4, the results can produce more evidence to support the influence of three factors which matter on surface appearance or gloss unit. Using 95% confidence interval, the p-value found for MT, HEN, and VI is less than 0.05. This three factors can be indicated on the main effect term on gloss appearance. In addition, the square term is significant for all factors but interaction term is not clearly relation on injection speed. Only on injection temperature could be influenced on interaction term.

Table 4. Estimated effects and coefficients for response surface methodology on gloss.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
MT	1	8.147	8.1471	16.86	0.003
HEN	1	74.707	74.7073	154.64	0
VI	1	3.121	3.1211	6.46	0.032
MT*MT	1	6.241	6.241	12.92	0.006
HEN*HEN	1	9.849	9.8486	20.39	0.001
VI*VI	1	8.754	8.7536	18.12	0.002
MT*HEN	1	18.743	18.7425	38.8	0
MT*VI	1	0.963	0.9626	1.99	0.192
HEN*VI	1	1.867	1.8673	3.87	0.081
Lack-of-Fit	5	2.88	0.576	1.57	0.341
Pure Error	4	1.468	0.3669		
Total	18	131.186			

The result of mathematical on RSM can be created as contour plot on figure 7 and surface plot in figure 8, both plots hold the value of VI at the center point of CCD. In that figure HEN become more is better on gloss appearance but on manufacturing ABS material can be used in the range of 200 - 240 °C, if temperature more than 240 °C effect opposite properties on gloss appearance may be dull surface. On MT parameter having effect followed by data analysis was chosen the level at 0.5 on experiments about 70 - 75 °C to best condition for mold temperature control.

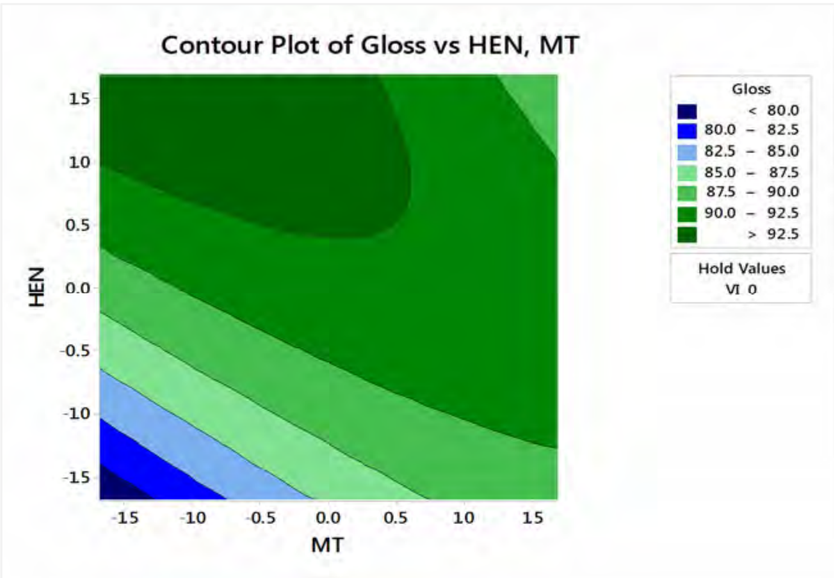

Figure 7. Contour plot of gloss unit on nozzle temperature and cavity temperature.

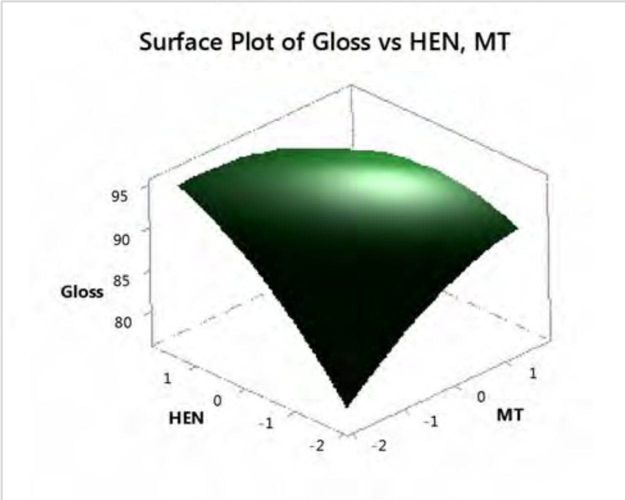

Figure 8. Surface plot of gloss unit on nozzle temperature and cavity temperature.

3.3 Mathematical modeling

For the experiment on gloss unit can predict equation to find the best condition, analyzed data output on R-square value is 96.69% total reliability can predicted equation on gloss unit. And reasonable data can check by lack of fit data shown in table 4, p-values is 0.341 more than 0.05 so that gloss unit equation can write in equation (3)

Gloss unit = 91.691 + 0.772 MT + 2.339 HEN + 0.478 VI - 0.676 MT*MT - 0.849 HEN*HEN - 0.801 VI*VI - 1.531 MT*HEN + 0.347 MT*VI + 0.483 HEN*VI (3)

3.4 Appearance of injection experimental

Appearance surface of ABS injection parts on gloss shown in figure 9, in the left part produced on low-temperature molding affected gloss surface part to opaque or not shine. The heater on molding temperature unit control cavity temperature equilibriums on each cycle can be produced gloss surface to be shiny and make more valuable on parts. In the experiment, comparison molding temperature between 40°C and 70°C respectively.

Figure 9. Comparison between ABS cover part on normal condition (left) and high heating processes (right).

4. Conclusion

In the present research study, the surface appearance of parts will be added value and more benefits on plastic injection parts. Heating molding by hot oil and water impingement cooling is developed to control the temperature of each cycle to constant. First cavity surface molding must be polished and shiny on proposed. Moreover, the injection parameter having the effect to gloss appearance on confidence interval. Base on the results, the following conclusions are obtained.

Parameter on thermal response was chosen on molding temperature and injection temperature. The result of independent variables on gloss surface is clearly confirmed by mathematics software has shown that injection temperature at end nozzle has the largest effect on gloss. The parameter of mold cavity temperature and injection speed was followed effects by respectively. The proposed method provides optimise value data using cavity temperature 70 ºC the injection temperature 240 ºC, and injection speed 120 mm/sec on 95% confidence interval.

However, this research setting center point of injection temperature (HEN) at 220 ºC cause of normal melt temperature of ABS plastic is 200 – 240 ºC. If adjust range of CCD upward on setting parameter it possible to make higher gloss appearance surface. So that concerned to cavity temperature when melt plastic was injected into cavity molding should be freezing or cooling stage behaviour on melt plastic to rigid plastic. The upper side of axis point of cavity temperature (MT) level is higher more than efficient rate of heating transfer out from melten plastic by cooling fluid. Due to cooling time too long in each cycle can be effect on shrinkage in finishing parts and gloss appearance could be reduce. And injection speed (VI) parameter make the high pressure in molding during injection cycle could be heat temperature up inside cavity but this parameter on previous research have too long can effect on warpage parts cause of gloss unit measure on parts will reduce too.

The future work will focus on designing and fabricating on RHCM technology with developed technology and proposed on new cavity insert for complicated shapes, and optimizing the another parameter to improve the heating and cooling efficiency, scratch proof and strength on plastic parts.

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