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대형 용해로의 외부 환경변수를 통제하기 위한 주변 환경관리의 활용

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Using Ambient Control to Prevent External Disturbances in Large-scale Furnace

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Large glass furnaces to produce glass for CRT are housed in huge chambers. It is costly to maintain such a chamber in constant temperature, humidity, and (air) pressure. In this study, first, we show that the process of such a huge furnace, which requires the steady maintenance of high temperature, is badly affected by the ambient temperature of surrounding air. Second, an alternative process which not only maintains the relatively constant temperature dispersion around the furnace, but is also economical will be proposed. We calculate the necessary volume of air inflow in the appendix.

Keywords : Control Chart, ARIMA, Furnace, Ambient Control

1. Intorduction

In relatively small glass furnaces such as those to produce thin glass for LCD are housed in relatively small chambers. It is not costly to maintain such a chamber in constant temperature, humidity, and (air) pressure. On the other hand, large glass furnace to produce glass for CRT are in the environment, where it is very costly to control the ambient air in constant temperature, humidity, and (air) pressure, since the chamber which houses it also has to be huge. In the meantime, in the inside of the glass furnace is melten glass with high degree of viscosity and non-random fluid characteristic. The result is, in most cases, poor quality and high defect rate. To make the matter worse, operators of the furnace tend to adjust the settings on the amount of auxiliary energies and oxygen used to make up for the changing external effects. However, it is not easy to monitor such complex a distribution of temperature over time, and build the statistical models for process analysis. The temperature is fluctuating in the short time interval and the fluctuation is presumably serially correlated, we need a statistical model to verify the statistical relations among relevant variables. As a convention, we select, among other variables, the temperature of the crown as reflecting the most the resultant quality characteristics.

Data that have an autocorrelation like the variables related to glass furnace operation cannot adopt X-RS chart, because

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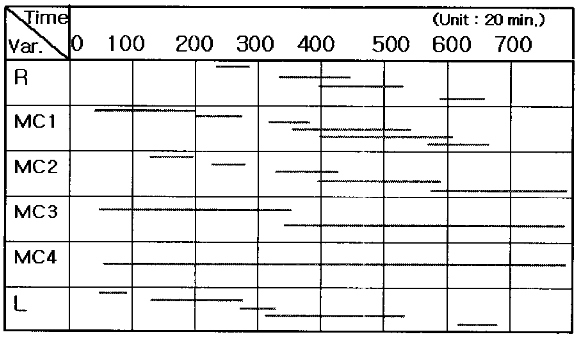
independent and identical error distribution is being assumed to implement the control chart. Therefore we use ARIMA model for diagnosis of process stability.

We only use the first step, identification, for diagnosis of process stability. The main tool used in this step is SACF (sample autocorrelation function) which is employed to check process stability. The stability, so called 'white noise', is defined as the acceptance of Ho : (=0, which means ACF=0. The white noise of the temperatures of the main crown in a glass furnace is shown in <Figure 1>.



<Figure 1> White noise of process variables(MC3: 3rd thermo couple in main crown)

<Figure 1> shows that, as a time-series, the glass furnace doesn't exhibit the stability. Why doesn't the glass furnace have the stability? There could be only one single reason; operators are changing continually the setting values in furnace operation in order to get spec-in. Why are operators changing the setting values? The reasons are primarily as follows; the fluctuations in the characteristics of incoming materials, the fluctuations in the environments surrounding the furnace such as temperature, moisture and pressure.

2. External Disturbances

We know that the quality characteristic like the temperature of the furnace is affected by the constantly changing dispersion of the air around it. In order to virtually get rid of this kind of fluctuation, for example, products produced by injection molding such as light guide panel of LCD, exterior parts of cellular phones are made in a clean chamber which has virtually constant temperature and moisture.

The effect of the surrounding air has been ignored in non-precision production. But the precision production requiring 5~10 μ standard deviation needs certain constant environment condition.

<Table 1> shows that, in Korea, the standard deviation of the air temperature in the rainy weather is lower than that in the clean day. And in the case of furnace process the non-conforming rate in the rainy weather is lower than that in the clean day (see <Table 2>).

<Table 1> The comparison of the temperature dispersion

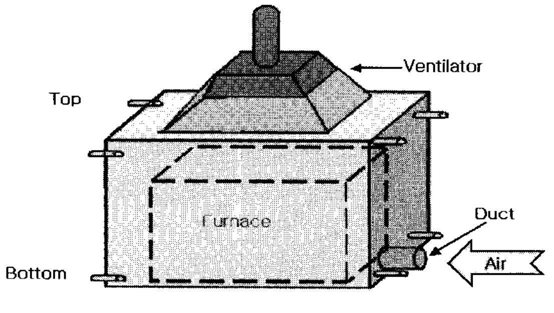
	Raining	Clean	P-value
Temperature SD/day(℃)	6.10	14.11	0.000

<Table 2> The comparison of the non-conforming rate

	Raining		Clean		P-value
	Mean	SD	Mean	SD	
A Line	16.44	4.81	16.81	6.55	0.742
B Line	18.75	6.80	21.23	9.04	0.108
C Line	32.00	10.40	33.81	6.74	0.269
D Line	23.10	14.70	29.40	16.40	0.040
E Line	19.47	9.02	23.80	15.10	0.073
F Line	24.52	6.17	28.17	8.13	0.009

3. Experiments

It is often affordable to have the injection molding process, which often happens in a relatively small-size shop, placed in the clean chamber. But that is not the case for a large furnace unless we find a new way of controling chamber environment which is efficient and economically compelling. In this study, first, we show that the furnace process which needs to maintain high temperature is very much affected by the cool surrounding air whose temperature is fluctuating. Second, an alternative, which maintains relatively constant temperature dispersion surrounding the furnace, while still economically feasible, will be proposed.



<Figure 2> Experimental model

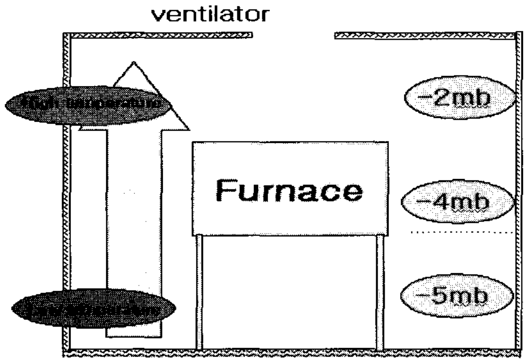
<Figure 2> is the experimental model testing the effect of the environment condition like air temperature.

Employing Taguchi method, we produced the result showing that, when the standard deviation of the temperature(20℃ ~30℃) surrounding the furnace is small, so is the temperature inside the furnace. And for the furnace process of high temperature inside a large chamber, the management of air current inside the chamber is important.

The air current should be smoothly flowing from the bottom to the top of the furnace house. <Figure 3> shows that the air temperature on the top of the house is higher than one at the bottom. Since the air pressure on the top would be higher, the air current tend to flow from the top to the bottom.

This fact indicates that, for the desired air-current to happen, we must get rid of the variation in the air pressure of the external air along with the variation in the moisture level.

To achieve it, first, we need to install insulating materials on the wall of the chamber. The external temperature outside the chamber usually shows large variations. This keeps such variations from affecting the ambient temperature inside the chamber.



<Figure 3> The status of the temperature and the pressure in the furnace house

Second, air ducts need to be installed to bring in the air from outside as can be seen in <Figure 2>. It will help push hot air out through the ventilator, instead of the air staying on the top, building pressure, keeping the top temperature higher than the lower part of the chamber. However, the air from outside has large variations, as said in the above. To reduce such variations, we need to install a water spray system which will mix the incoming air with water. As discussed in Section 2, our research shows that temperature dispersion is smaller on rainy days, because moisture in the air keep the temperature variation down. We are applying this insight to our problem. In addition, this will also remove dirts from incoming air. This way, external disturbances due to incoming air can be greatly reduced.

During the winter season, we have another complication. The furnace is operated in a virtually sealed chamber, which leads to the reverse airflow, the air on the top of the chamber flowing back to the bottom, as discussed above. For this reason, the chamber needs to take in the air from outside, but it is much colder than the air inside. To heat up the incoming air using heaters would be quite costly for the chamber housing a large furnace. Instead we reroute part of the hot air on the top, which could otherwise flow out through the ventilator, and mix it with incoming cold air from the air duct at the bottom. This could be a cost-effective solution to the reverse air flow problem described above. This would also lead to an additional benefit: it would prevent the freezing of moisture injected into the incoming air by water spray system.

This will significantly reduce the ambient temperature variation of the large glass furnace by minimizing external disturbances.

4. Conclusion

The control of the air current can provide a cost-effective method to ensure the good operating conditions for the large glass furnace, which can stabilize the moisture and air pressure level as well as the inflowing air temperature level.

We showed three different kinds of ways to address this problem. The first is to install insulating materials on the wall of the chamber. This way, the large variation of outside air temperature would not affect the air inside a chamber much. The second is to spray water to the air coming in from outside via air duct. Mixing moisture with air would also reduce the temperature variation of air from outside. The third is to mix part of hot air from inside with cold incoming air from outside in order to prevent the growing temperature variation due to incoming air.

We may now repeat to give the outline of our research direction. Whenever external disturbance occurs, operators respond with appropriate adjustments to keep the furnace in a steady environment. It is called reactive control. If a furnace can be maintained in constant temperature, humidity, and (air) pressure, we could eliminate external disturbance. This is called preventive control. In precision processes that require (5～10)

μ-level standard deviation, if the environmental factors such as temperature, moisture and air pressure are controlled to meet such a stringent requirement, it is called predictive control. If reactive, preventive, predictive control can be all realized, it is called proactive control. We believe that, in an instrumental process, the proactive control can be achieved by using ambient control to effectively eliminate external disturbances. It is our hope that our further research would lead to the eventual realization of proactive control.

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Appendix

Calculating the required volume of air inflow

Let us assume that (1) the external air would flow into the chamber from air ducts at the side of the chamber, (2) the top of the chamber is open, through which the air inside the chamber would flow out, and (3) the furnace is located in the middle of the chamber, generating heat. We will calculate the temperature change over time inside the chamber. This result will be used to find out the required volume of air inflow into the chamber.

Let C_v be the heat capacity of air, V_r be the air volume inside the chamber. If the temperature of air changes, it could also change heat capacity of air, but it can be safely ignored when the temperature is around 20℃. We could also use volume instead of mass because, in the case of our interest, the temperature change of air has negligible effect on air volume.

We further define parameters as follows:

$T(t)$: the temperature of air inside the chamber at time t,
V_w : the volume of air inflow per time unit dt,
T_w : the temperature of air inflow,
q : the amount of heat generated by the furnace per time unit dt.

Let $T+dT$ be the temperature inside the chamber at time $t+dt$. Then the amount of heat generated by the furnace between time t and $t+dt$ is qdt, the amount of heat absorbed by the cold air inflow is $(T+dT-T_w)C_vV_wdt$, and the one absorbed by the air inside the chamber is dTC_vV_r. In setting up this formula, we ignored the differential terms beyond first order.

Since the heat generated by the furnace is equal to the heat absorbed both by cold air inflow and air inside the chamber, we have:

$$qdt=(T-T_w)C_vV_wdt+C_vV_rdT \cdots\cdots \tag{1}$$

or to put it another way,

$$q=(T-T_w)C_vV_w+C_vV_rdT/dt \cdots\cdots \tag{2}$$

Let

$$T=x+\frac{q}{C_vV_w}+T_w \cdots\cdots \tag{3}$$

$$xC_vV_w+C_vV_rdx/dt=0 \cdots\cdots \tag{4}$$

Solving Eq. (4) we have

$$x(t)=x_0e^{-\frac{V_w}{V_r}t} \cdots\cdots \tag{5}$$

Substituting it for x's in Eq. (3), we get

$$T(t)=x_0e^{-\frac{V_w}{V_r}t}+\frac{q}{C_vV_w}+T_w \cdots\cdots \tag{6}$$

Let T_0 be the temperature of the chamber at $t=0$. From Eq. (6), we have

$$T(t)=\left(T_0-T_w-\frac{q}{C_v V_w}\right)e^{-\frac{V_w}{V_r}t}+\frac{q}{C_v V_w}+T_w \quad\text{......} (7)$$

Let us consider some special case of this formula.

(1) As $t\to\infty$, $T\to\frac{q}{C_v V_w}+T_w$.

(2) With no cold air inflow (i.e., $V_w=0$),

$$T(t)=T_0+\frac{q}{C_v V_r}t\ .$$

(3) With no heat from the furnace,

$T(t)=(T_0-T_w)e^{-\frac{V_w}{V_r}t}+T_w$. As $t\to\infty$, $T\to T_w$.

That is, the temperature inside the chamber converges to the temperature of air inflow from outside.

To calculate the volume of air inflow, we need to use the case (1). That is, the target temperature T^{∇} we need to maintain is $T^{\nabla}=\frac{q}{C_v V_w}+T_w$.

Solving this equation in terms of V_w,

$$V_w=\frac{q}{C_v\times(T^{\nabla}-T_w)}\ .$$

$\frac{q}{C_v\times(T^{\nabla}-T_w)}$ is the volume of air inflow from outside, given T_w, the temperature of air inflow, T^{∇}, the target temperature, q, the heat generated by the furnace per time unit *dt*, and C_v, the heat capacity of air.