DRYING OF PAINTED GLASS PLATE ON MOVING TAPE

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While moving on the tape, the surface temperature of the painted glass plate entering the drying oven reaches a required certain temperature after a certain distance. The drying air as reverse flow through the product is directed transversely across the other end of the drying oven and towards the inlet. The convective mass transfer between the surface and the free flow depends on the conditions within the boundary layer. The relationship between convection mass transfer and concentration boundary layer are explained with valid equations for mol flux related to diffusion mass transfer. In the study, drying oven and air conditioning cabin has been used to determine the drying properties of two types of tempered glass paint of 1T1405-IR702 and 1T1430-IR702. In the drying process on conveyor tape, the drying oven length has been determined between 5.30 m and 23.3 m for values of conveyor tape velocity of 0.05 m/s, drying temperatures between 50 °C and 70 °C and forced air velocity of 2.5 m/s. At the end of the study, the theoretical and experimental results have also been evaluated.

Key words*: glass paint, forced drying, mass transfer with diffusion*.

1. Introduction

National and international competition conditions entail to reducing the costs of a product. The most important input is energy with raw material in the many production processes. Nowadays, the automotive sector is at the beginning of the sectors where competition is most intense. This case in the sector is valid for supplier industry and also especially for the production of automotive glass.

When investigated the production processes of automotive glass, it is understood that parameters which are related product quality and product cycle time and spent energy affecting the production performance are temperature, pressure and time. It is required to select these parameters in every stage as true for a production with accuracy and low cost.

In this study, glass paint drying process that is one important stage of production of automotive glass is taken into account as energy intense process and carried out studies are explained for optimization of process.

The aim of the study is to obtain a theoretical model of the mass transfer process, to determine mass transfer amount occurred in the oven and to compare with the theoretical model and to carry out optimization parameters of the drying oven for improving mass transfer phenomena (drying process). There are articles and information - theoretically on this subject in the literature [1], [2], [3], [14], [15], [16], [17]. However, article and practical work on glass painting and its automation in large quantities are rather less. Theoretical modeling and experimental study have been carried out in both university and industry by using same paints for natural drying process [4]. In particular, it is understood that applied studies are in the form of prediction and copying without any theoretical basis. The study about this subject has been welcomed both as a paper presented at the scientific meeting and as an article in the SCI journal [5].

2. Theoretical Fundamentals

It is known that factor causing heat transfer in any environment is a temperature difference between this environment and another. Similarly, when there is a concentration difference in an environment, mass transfer becomes occurs. In other words, temperature and concentration differences are compelling factors for heat and mass transfer, respectively [6]. Fick law is used for the mathematical model relating to mass transfer [1]. Simplified correlations are valid according to Fick's law if the total mass density ρ and total molar concentration C are constant and there is one dimensional mol transfer, as follows.

$$\bar{\dot{n}}_A = \frac{\dot{m}_A}{M} = -D\frac{dC_A}{dy} \qquad (1)$$

Here, D_{AB} is an important transfer property regarding mixture called as diffusion coefficient or mass diffusivity. D_{AB}, mass diffusion coefficient: variable studies are carried out to determine mass diffusion coefficient for binary mixtures as A and B composed of two different gases [7], [4]. Diffusion coefficient which is utilizable for certain pressure and temperature ranges can be described by benefiting from kinetic gas theory with assuming ideal gas, [8].

$$D_{AB} \cong p^{-1}T^{3/2} \qquad (2)$$

This equation describing diffusion of A miscible (here solvent) in B miscible (here air) is function of variables as temperature, pressure and mixture values. Molar flux of A component shown with $\bar{\dot{n}}_A \left(\mathrm{kmol/m^2s}\right)$ is proportional with total molar concentration of mixture $C = C_A + C_B\ (\mathrm{kmol/m^3})$ and gradient of component molecular ratio $C_A = C_A / C$.

During drying, one of components –solvent– is transferred from one phase, dried painted glass, to another, for example dryer air. Transfer event is pointed out with Figure 1 at during drying.

Moving band

Figure 1. Drying of painted glass

Drying oven can be considered in two ways: a painted glass enters to oven environment heated to the required temperature on the moving band and dries with natural convection, in another way; it is dried by sending the heated drying air to the required temperature environment to the same or reverse direction.

It can be accepted that the mass transfer becomes by natural convection when not sending air in the drying oven while feed rate is taken into consideration as 0.055 m/s. The expression giving the mass transfer is described as follows:

$$\bar{\dot{m}}_A = \beta.F.\rho\left(Y_{Ao} - Y_{A\infty}\right) \tag{3}$$

Here; when *β, F, ρ* indicate mass transfer number, the total area covered from paint on the glass, mean density of air in oven atmosphere and on paint film, respectively, Y_{Ao} and $Y_{\mathrm{A}\infty}$ are solvent concentration on the paint film and in the oven environment, respectively.

3. Design Problem Description

Due to national and international rivalry conditions, chemical contents of ceramic and silver print pastes which are used in automotive glasses are kept as secret. Therefore, it is not possible to know physical values such as molecular mass of paints in question, partial evaporation pressure etc. Detection of drying properties of automotive glass paints is possible as experimentally. While drying properties of the glass paints that have been obtained from the supplier in Trakya Auto Glass Factory have been determined in experimental studies, it has been used “Thermogravimetric Analysis Method (TGA)”. Here, effective elements have been investigated by separating two groups. When elements relating to measurement system are heating ratio, oven atmosphere, geometry of oven and sample vessel and material of sample vessel, elements related to material properties are mass, particle magnitude, sample preliminary, package, heat transfer ability and reaction heat.

Drying oven characteristic values are given as 25 °C, 28 °C, 72 °C, 150 °C and 0.055 m/s for temperature with painted at inlet, inlet and outlet temperatures of painted glass, environment temperature of drying oven and conveyor tape velocity, respectively.

Assumptions: concentration of solvent vapor found in atmosphere at drying oven environment is level of “ppm” and therefore $Y_{\mathrm{A}\infty} = 0$ is accepted by neglecting solvent vapor existed in oven atmosphere.

The calculation has been done with two different approaches for paint film surface temperature, it is as follows:

1* The first approach is mean of the inlet and outlet temperatures T_{mean} = (25+70)/2 = 47.5 °C as surface temperature of the paint film.

2* The second approach is that paint film is heated to 70 °C immediately after entering the oven.

The density of air in the drying oven atmosphere has been taken as mean densities of air at paint film and oven temperature

Solvent concentration immediately above the paint film has been accepted as 100 % and Y_{Ao} has been described as $Y_{Ao} = p_{solv.} / p$

4. Experimental Studies and Calculations

Knowing of D_{AB} diffusion coefficient is necessary to determine *β* mass transition number to be a benefit in calculations. In the scope of this study, the topic that is given the most attention is to determine diffusion coefficient. When examining the table given by Incropera, it is seen that diffusion coefficient of different gases in air changes between 0.28×10^{-4} and 0.11×10^{-4} m^2/s, [2]. It is understood that diffusion coefficient value is required to be about 0.15×10^{-4} m^2/s considering the table in question since the solvent vapor also diffuses through the air.

According to reference [2], the following explanation can be given. Experimental studies have been carried out by several investigators to determine the mass diffusion coefficient (D_{AB}) for binary mixtures of two gases such as A and B.

By using the perfect gas assumption and the kinetic gas theory, for the diffusion coefficient, it can be shown that th equation 2 is valid,. In this equation, *p* [at] is mixture pressure and *T* [K] is mixture temperature.

Bird et al. has extensively studied the theoretical work on this subject and their comparison with experimental findings [9], [10], [11].

In some mixtures, experimental findings of the binary components are presented in the table 1 [2].

Table 1. Experimental findings of the binary components

Material A	Material B	T(K)	D_{AB} (m^2/s)
NH_3	Air	298	$0.28x10^{-4}$
H_2O	Air	298	$0.26x10^{-4}$
CO_2	Air	298	$0.16x10^{-4}$
H_2	Air	298	$0.41x10^{-4}$
O_2	Air	298	$0.21x10^{-4}$
Ar	N_2	293	$0.19x10^{-4}$
H_2	O_2	273	$0.70x10^{-4}$
H_2	N_2	273	$0.68x10^{-4}$
CO_2	N_2	293	$0.16x10^{-4}$
CO_2	O_2	273	$0.14x10^{-4}$
O_2	N_2	273	$0.18x10^{-4}$

As the table shows, the value for CO_2 is given as 0.16 * 10-4 m^2 / s. The experimental value D_{AB} for solvent in this paper is different from the value given for CO_2. The mass conservation principle was used when diffusion coefficient of the solvent was determined under 1 at pressure in the air. Two-stage experimental study was done at 50 °C and 70 °C temperatures, while the diffusion coefficient (D_{AB}) of solvent was determined.

In stage 1; Thermogravimetric analysis was performed to verify the validity of the water vapor diffusion coefficient ($D_{AB} = 0.26*10^{-4} m^2/s$) in air. The device produced by Metler – Toledo company was used. The dried product was weighed at intervals of two minutes and the mass reduction was measured.

In stage 2; The large part of the paint is solvent. Similar product was painted with solvent dye and similar thermogravimetric analysis was repeated. Again, the dried product was weighed at intervals of two minutes and the mass reduction was measured.

The diffusion coefficient of the solvent in the air and the partial saturation pressure of the solvent were determined with using experimental figure given in Figure 2 in the article.

Partial evaporation pressure values of solvent are not known for operating temperatures belonging to glass drying oven. A method has been improved in which solvent partial vapor pressures can be calculated by benefiting from mass transition mathematical model and experimental study results for operating temperatures.

According to mathematical model, mass transition is described as follows [2]:

$$\dot{m}_A = \frac{pD_{AB}}{R_A T} \ln \frac{1-Y_{A,\infty}}{1-Y_{A,o}} \tag{4}$$

Evaporation amount is found as thermogravimetric experimental and a fixed value for expression containing logarithm is obtained with writing is known physical values in an equation. Then the expression can be simplified by taking the entlogarithm and also mol ratios can be written by using pressure ratios.

$$\ln \frac{1-Y_{A,\infty}}{1-Y_{A,o}} = J(cons.) \tag{5}$$

$$e^J = \frac{1-Y_{A,\infty}}{1-Y_{A,o}} \tag{6}$$

$$Y_{A,\infty} = \varphi_\infty \frac{p_A}{p} \quad \text{and} \quad Y_{A,o} = \varphi_o \frac{p_A}{p} \tag{7}$$

$$e^J = \frac{1-\varphi_{A\infty} \dfrac{p_{A\infty}}{p}}{1-\varphi_{Ao} \dfrac{p_{Ao}}{p}} \tag{8}$$

Due to the complexity of the found of this expression, it is not easy to find value of p_A. Therefore, the graph shown in Figure 2 is plotted by calculating e^J values corresponding to different p_A values, using a computer, [12]. Obtained e^J value has been marked in the graph according to thermogravimetric determination of mass transition amount and p_A value has been found for related temperature value as shown with arrows. The abscissa is the saturation pressure of the solvent in Figure 2. As can be understood from the equations detailed previously for equation (4), the graph in Figure 2 is plotted by using the results determined by thermogravimetric analysis for temperatures of 50 ° C and 70 ° C.

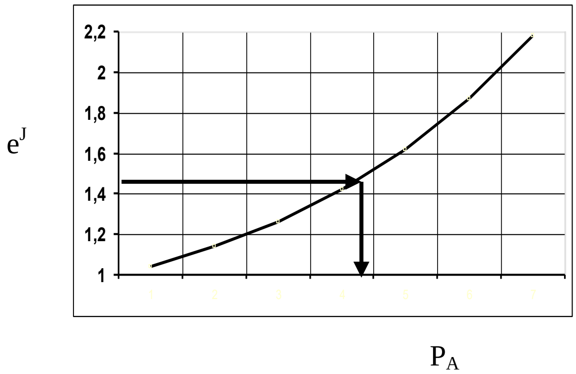

Figure 2. Experimental determination of partial evaporation pressure

4.1 The glass paint drying with natural convection

IR701A and IR702A found in the structure of paints produced by Johnson Matthey firm have been alone provided in the experimental studies carried out for determining drying rate of paint on the glass surface. It has been provided evaporation of both organic mediums by heating one each in crucible. Variations in their mass have been recorded depending on time. The experiments have been done for 50 °C and 70 °C temperatures given drying oven operating conditions (Figs.3 and 4).

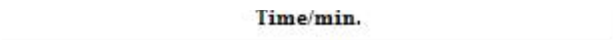

Figure 3. Temporal evaporation amount for 701A and 702A mediums at 50 °C

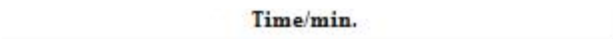

Figure 4. Temporal evaporation amount for 701A and 702A mediums at 70 °C

Mean evaporation rates from unit surfaces of mediums at both temperature values have been calculated by benefiting from experimental datas and surface area of test container and given in Table 2.

Table 2. Evaporation amounts from unit surface for 701A and 702A mediums

	701A	702A
50 °C	2.06 g/(m^2min)	1.31 g/(m^2min)
70 °C	5.72 g/(m^2 min)	4.59 g/(m^2 min)

It has been required to determine paint in the unit area and medium amount related to this in order to indicate drying rate of paint on the glass surface. Paint amount in the unit area can be determined from paint thickness on the glass surface. The paint thickness on the glass has been measured with wet film thickness measurement method as 25 microns.

Paint mass on the glass has been calculated as 60 g/m^2 by considering 2400 kg/m^3 value for enamel paint densities. The firm has given 17% by mass of the paint as organic medium. According to this, medium mass on the glass has been calculated as 10.2 g/m^2. Temporal variations of medium mass on the glass surface which states drying ratio of paint at operating temperatures have been given in Table 3.

Table 3. Variation of the medium mass, g/m^2, on the glass surface according to temperature

	701A		702A	
Period, s	50 °C	70 °C	50 °C	70 °C
0	10.2	10.2	10.2	10.2
30	9.17	7.34	9.55	7.91
60	8.14	4.48	8.89	5.61
90	7.11	1.62	8.24	3.32
120	6.08		7.58	1.02
150	5.05		6.93	
180	4.02		6.27	
210	2.99		5.62	
240	1.96		4.96	
270	0.93		4.31	
300			3.65	
330			2.99	
360			2.34	
390			1.69	
420			1.03	
450			0.38	

The glass paint drying process is a continuous operation. After the glass is painted in printing machine, it is reaches to drying oven by means of a conveyor and it is dried with natural convection while being inside the drying oven. The velocity of the drying oven conveyor must be conformed with the printing machine velocity. Therefore, the period which have stayed inside the drying oven of the glass can be determined with conveyor tape length inside the drying oven. Determined necessary lengths of a drying oven that has conveyor velocity of 0.055 m/s for different temperature values and medium types have been shown in Table 4 by benefiting from obtained experimental data.

Table 4. Lengths of the drying oven according to drying temperature and medium type

Drying temperature / Medium	Drying oven length, m
50 °C / 701A	14.85
70 °C / 701A	5.30
50 °C / 702A	23.3
70 °C / 702A	6.60

4.2 The glass paint drying with forced convection

The experimental studies have been carried out in order to determine the effect of forced convection on glass paint drying process. While mediums with 701A and 702A code have been vaporized in tests, air flow that has certain velocity has been formed and air velocity has been selected as 2.5 m/s. Experiment temperatures have been kept at values of 50 °C and 70 °C to make a comparison. Decrease in medium mass has been determined by carrying out measurement with certain period interval similar to experimental studies done with natural convection. Evaporation amount and related to this, the rate of drying have been determined to increase due to moving of air during drying. Variation values of medium evaporation rate have been given in Table 5 according to drying temperature and air velocity.

Table 5. Medium evaporation rate according to drying temperature and air velocity

Drying temperature / drying air velocity	701 A Evaporation velocity	702 A Evaporation velocity
50 °C v = 0 m/s	2.06 $g/(m^2 min)$	1.31 $g/(m^2 min)$
70 °C v = 0 m/s	5.72 $g/(m^2 min)$	4.59 $g/(m^2 min)$
50 °C v = 2.5 m/s	3.17 $g/(m^2 min)$	2.33 $g/(m^2 min)$
70 °C v = 2.5 m/s	14.15 $g/(m^2 min)$	10.60 $g/(m^2 min)$

Variation of oven dimension that will affect the first investment and operating cost of drying oven has been given in Table 6 depending on drying temperature and air velocity.

Table 6. Variation of drying oven length according to drying temperatre and air velocity

Drying temperature / drying air velocity	701 A Drying oven length	702 A Drying oven length
50 °C v = 0 m/s	14.85 m	23.30 m
70 °C v = 0 m/s	5.30 m	6.60 m
50 °C v = 2.5 m/s	9.65 m	13.10 m
70 °C v = 2.5 m/s	2.16 m	2.88 m

5. Cooling section design of drying oven

Heat convection becoming between glass and air during cooling processing has been investigated in two different ways by means of impinging jet flow model to a surface and a Fluent computer program. Comprehensive investigation of the convection coefficient data for impinging jet flow model has been carried out by Martin [13]. Nusselt correlations have been described for slot nozzle and nozzle serials or a single round, [3].

$$\frac{Nu}{\mathrm{Pr}^{0.42}} = G\left(\frac{r}{D}, \frac{H}{W}\right) F_1(\mathrm{Re}) \text{ for round nozzle} \tag{9}$$

$$\frac{Nu}{\mathrm{Pr}^{0.42}} = \frac{3.06}{\frac{x}{W} + \frac{H}{W} + 2.78} \mathrm{Re}^m \quad \text{for slot nozzle} \tag{10a}$$

m is defined as follows in the source of the equation [6].

$$m = 0.695 - \left[\left(\frac{x}{2W}\right) + \left(\frac{H}{2W}\right)^{1.33} + 3.06\right]^{-1} \tag{10b}$$

$$\frac{Nu}{\mathrm{Pr}^{0.42}} = K\left(A_r, \frac{H}{D}\right) G\left(A_r, \frac{H}{D}\right) F_2(\mathrm{Re}) \text{ for round nozzle serials} \tag{11a}$$

The meanings of the symbols used in the article are as follows.

$$A_r = \frac{\pi D^2}{4S^2} \quad S\text{: distance between nozzles} \tag{11b}$$

$$G = 2A_r^{1/2}\frac{1-2.2A_r^{1/2}}{1+0.2\left(\frac{H}{D}-6\right)A_r^{1/2}} \tag{11c}$$

$$K = \left(1+\left(\frac{\frac{H}{D}}{\frac{0.6}{A_r^{1/2}}}\right)^6\right)^{-0.05} \tag{11d}$$

$$F_2 = \mathrm{Re}^{2/3} \tag{11e}$$

In the circular nozzle, a parallel flow to the circular surface occurs as a result of the air jet hitting perpendicular to the surface. When this flow is fully formed, its radius is shown by *r*. In the slotted nozzle, parallel flow to horizontal opposite surface occurs after the air jet has hit the surface perpendicular. Distance is shown by *x* when this flow is fully formed.

K, *G*, A_r, and F_2 used in the expressions have been described as follows. *H* is distance between nozzle nib and part to be cooled. *W* is equivalent diameter to be taken instead of diameter in the slotted nozzle. *D* is nozzle slot diameter and *S* is distance between two nozzles. Expressions are valid for ranges of $2000 \le \mathrm{Re} \le 100000$, $2 \le H/D \le 12$, $0.004 \le A_r \le 0.04$.

$$A_r = \frac{\pi D^2}{4S^2} \tag{12}$$

$$G = 2A_r^{1/2}\frac{1-2.2A_r^{1/2}}{1+0.2\left(\frac{H}{D}-6\right)A_r^{1/2}} \tag{13}$$

$$K = \left(1+\left(\frac{\frac{H}{D}}{\frac{0.6}{A_r^{1/2}}}\right)^6\right)^{-0.05} \tag{14}$$

$$F_2 = Re^{2/3} \tag{15}$$

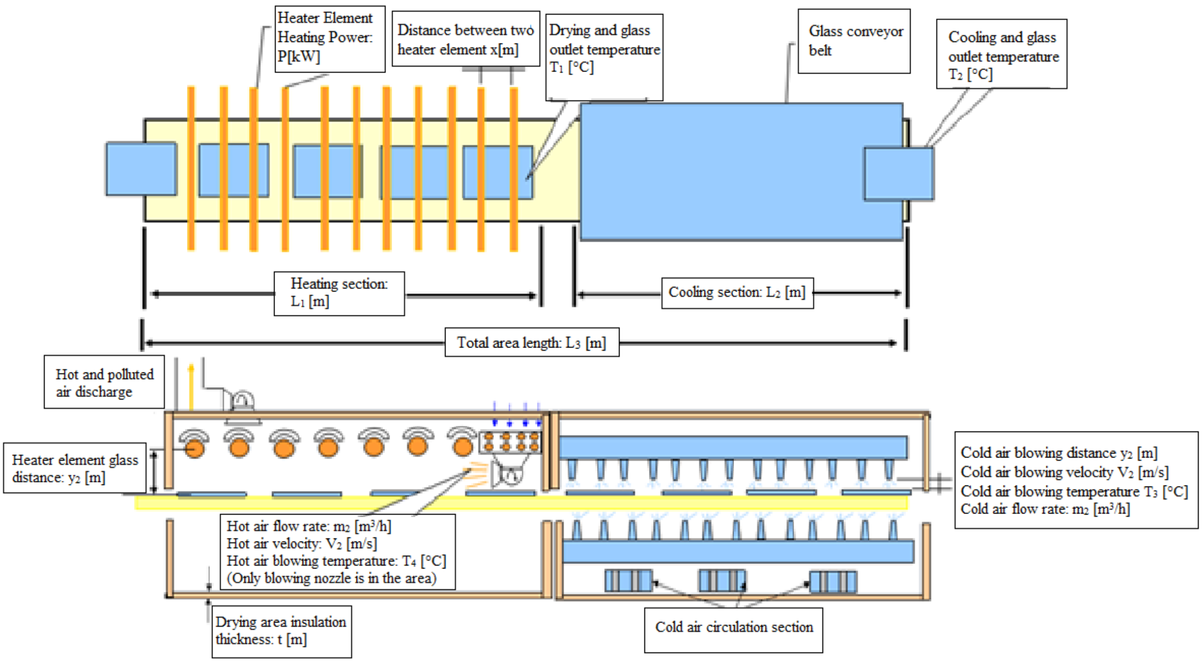

Figure 5. Glass paint drying and cooling section on the moving tape

Transfer of the glass at the heating and cooling sections in the glass paint drying oven has been carried out by a conveyor with moving tape manufactured from temperature resistant kevlar material. A single conveyor tape has been used for heating and cooling sections. Blowing boxes with nozzle in which cooling air is blown have been placed above and bottom of the conveyor tape. Heat convection coefficient, α can be calculated by using obtained *Nu* number value.

$$Nu = \frac{\alpha D}{\lambda} \tag{16}$$

Drying and cooling sections by heating belonging to glass paint drying oven is shown as schematic in Figure 5.

The glass that has been carried out printing paint, after the drying oven in order to reach asked temperature at outlet of the cooling section, tape length that should be in the cooling section changes with geometric magnitudes and cooling air temperature.

Datas belonging to nozzle are D = 0.01 – 0.025 m, S = 0.14 m, H = 0,1 m and datas related with air are blowing velocity range v = 2 m/s and 5 m/s, T_∞ = 288 K, kinematic viscosity, thermal conductivity and *Pr* number are υ = 0.000013 m^2/s, λ = 0.0233 W/(mK) and Pr = 0.71, respectively.

The obtained values by calculation for different values of cooling air velocity and nozzle diameter have been given in Table 7.

6. Cooling time and conveyor tape length calculation of the cooling section

It has been asked to be 25 °C of the temperature in the symmetry axis of the glass at the outlet of the cooling section. The cooling time has been calculated for every different value of heat convection coefficient by benefiting from the Heissler diagram in Figure 6. For the glass density ρ = 2500 kg/m^3, specific heat capacity c_p = 750 J/(kgK), thermal conductivity λ =1.4 W/(mK), thickness L = 0.002 m and temperatures T_o= 25 °C, T_∞=15 ^{o}C, T_i= 80 °C are valid.

Table 7. Geometric Measurements and Calculated Values of Cooling Section

Air Velocity, Nozzle Diameter m/s , m	Nu	α Heat Convection Coefficient W/m^{2}K	$\dot{V}$ Nozzle air consumption m^3/s
v = 2, d =0.01	6.15	14.33	0.57
v = 2, d =0.015	11.96	18.58	1.27
v = 2, d =0.02	19.01	22.15	2.26
v = 2, d =0.025	27.01	25.15	3.53
v = 3, d =0.01	8.06	18.78	0.85
v = 3, d =0.015	15.67	24.43	1.91
v = 3, d =0.02	24.91	29.03	3.39
v = 3, d =0.025	35.11	32.99	5.30
v = 4, d =0.01	9.76	22.70	1.13
v = 4, d =0.015	18.98	29.49	2.54
v = 4, d =0.02	30.18	35.16	4.52
v = 4, d =0.025	42.88	39.90	7.07
v = 5, d =0.01	11.33	26.41	1.41
v = 5, d =0.015	22.03	34.22	3.18
v = 5, d =0.02	35.03	40.80	5.65
v = 5, d =0.025	49.76	46.38	8.83

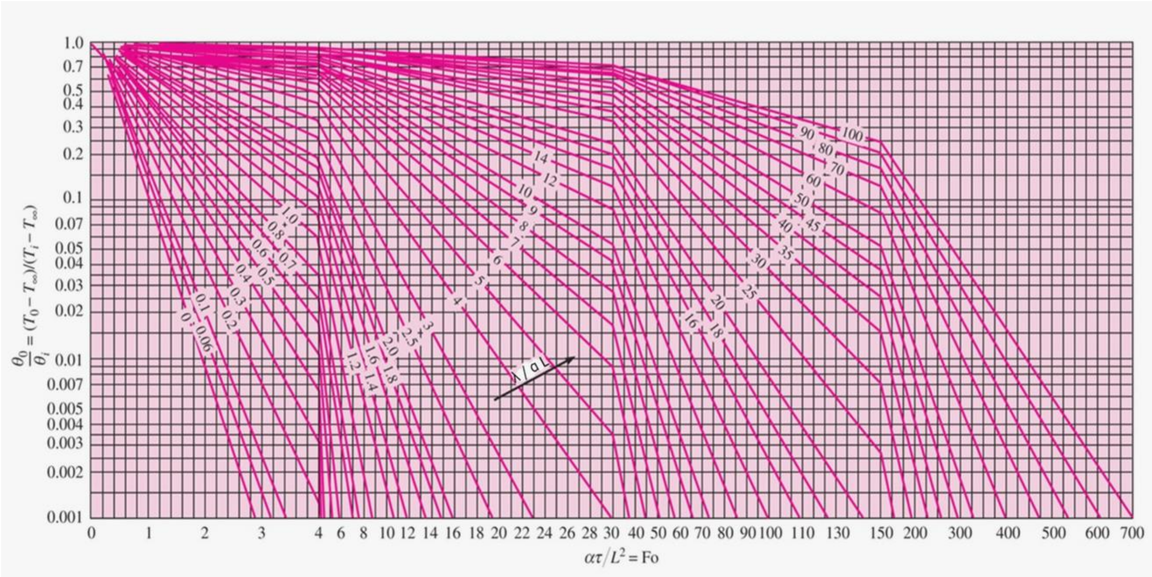

Figure 6. Diagram of Heissler

For calculating the cooling time, ratios of $(T_o-T_\infty)/(T_i-T_\infty)$ and $(\lambda/\alpha L)$ are calculated. Afterwards, $(a.t/L^2)$ is read from the diagram. Cooling period, conveyor tape lengths and air comsumption amounts for different values of heat convection coefficient have been given in table 8.

Table 8. Cooling Period, Conveyor Tape Lengths and Air Consumption Amounts for Different Values of Convection Heat Transfer Coefficient

v, D air velocity, nozzle diameter m/s , m	Nu	α, Heat convection coefficient $W/(m^2K)$	t, cooling Time s	l tape length m	$\dot{V}$, air volume flow rate through the nozzle m^3/s	Consumption Total
v = 2 d = 0.01	6.15	14.33	482.0	24.10	0.57	13.62
v = 2 d = 0.015	11.96	18.58	391.0	19.55	1.27	24.86
v = 2 d = 0.02	19.01	22.15	321.0	16.05	2.26	36.29
v = 2 d = 0.025	27.01	25.15	289.0	14.45	3.53	51.04
v = 3 d =0.01	8.06	18.78	391.0	19.55	0.85	16.57
v = 3 d =0.015	15.67	24.43	305.0	15.25	1.91	29.09

v = 3 *d* =0.02	24.91	29.03	262.5	13.13	3.39	44.51
v = 3 d =0.025	35.11	32.99	217.0	10.85	5.30	57.48
v = 4 *d* =0.01	9.76	22.70	321.0	16.05	1.13	18.14
v = 4 *d* =0.015	18.98	29.49	262.0	13.10	2.54	33.32
w = 4 *d* =0.02	30.18	35.16	214.0	10.70	4.52	48.38
v = 4 d =0.025	42.88	39.90	187.5	9.38	7.07	66.23
v = 5 *d* =0.01	11.33	26.41	273.0	13.65	1.41	19.29
v = 5 *d* =0.015	22.03	34.22	214.0	10.70	3.18	34.02
v = 5 *d* =0.02	35.03	40.80	187.5	9.38	5.65	52.99
v = 5 *d* =0.025	49.76	46.38	160.0	8.00	8.83	70.65

After temperature has been calculated according to expression of transfer nummer value $a = \lambda_{glass} / \rho_{glass} . c_{glass}$ cooling time is determined.

The flow rate is shown by v in Table 8. Flow rate values were selected as 2, 3, 4 and 5 m / s. The nozzle diameter (*d*) measurements were taken as four different values of 0.01, 0.015, 0.02 and 0.025 m. The group was formed as a diameter with a flow rate. Then, the total air consumption is calculated over respectively Nusselt number, heat transfer number, cooling time, conveyor size, air consumption for a nozzle and the number of the nozzles along the conveyor belt.

7. Result and Evaluation

The glass paint drying process that has wide application area in the automotive sector has been investigated in the scope of process optimization and the carried out experimental studies have been explained, intended for determining of drying properties of the paints. A mathematical model has been formed with the experimentally obtained data. The formed mathematical model includes variables that have influence in the drying process of glass paint such as temperature, drying time and air velocity for drying. The effects of the variation of variables of operation which will describe drying process as numerical on the product quality and consumed energy amount have been calculable.

It has been seen that the drying velocity is high for a constant temperature with forming forced air movement in the printing operation for drying paint transferred to glass and also the tape length of drying oven has been decreased. This result is meant to be an advantage in terms of the first investment and operation costs. As secondly, it has been determined that drying rate has increased with forced air motion in the paint drying oven. It has been understood that this will be an advantage in terms of drying and operation costs at the lower temperatures.

After the paint on surface of the moving glass on the tape has been dried by heating, its cooling has been carried out. The effect of variation of similar parameters such as the effective air velocity and temperature, nozzle diameter, distance between nozzle and glass on the cooling process during the cooling of the glass has been explained. The glass cooling process has been analyzed in two different ways. In the first, the results have been found by using Heissler diagram. In the second, the glass cooling process has been analyzed by using computer program depending on the finite element method. Results close to each other have been obtained in both methods. It has been determined that in the cases of the increasing the air velocity or raising of the nozzle diameter, the convection coefficient between the glass and air has increased, the required time for the cooling has reduced, and also the air consumption has increased. According to these, the first investment and operating costs belonging the system have been highly improved for cooling of the glass in the asked time.

Only the edges, not the whole surface of the windshield and rear windshield of various vehicle types, such as cars, buses and trucks are painted. The inside surfaces of the rear windshield of some vehicles are painted with stripes which like resistance. The condensed water on the inner surface of the windows is removed with the evaporation which occurs through the resistance.

During the mass production, this partial painting must be good quality and the dye which is like line should not be broken after the drying. These two factors are the important matters for the clients to accept the car of which windshield or rear windshield will be replaced. In the volume made of paint, fresh air is required especially in terms of solid particles. The solvent vapor which is released after the drying of the paint which is after very applied on the glass is removed properly with the air stream.

The next steps need to be carried out in two ways. The first group of actions includes the optimization of the parameters which affect the radiant heating of the product in the shape of window on the conveyor belt. The second group of actions includes defining the correct height for drying kiln, adding suitable by-pass unit to drying air-duct and enabling the change the speed of the supply air according to the type of the product while drying.

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Nomenclature

$\dot{n}$	Molar flux, kmol/(m^{2}s)
$\dot{m}$	Mass flux, kg/ m^{2}s
M	Molar mass, kg/mol
D	Diffusion coefficient, m^2/s
d	Nozzle diameter, m
p	Pressure, Pa,
T	Temperature, °C, K
C	Concentration
β	Substance transition number, m/s
F	Area, m^2
ρ	Density, kg/m^3
Y	Molar ratio
φ	Relative humidity of air

G	Coefficient depending on geometric measurement
A_r	Coefficient depending on geometric measurement
K	Coefficient depending on geometric measurement
v	Drying air velocity, m/s
υ	Kinematic viscosity, m^2 / s
Re	Reynolds number
Nu	Nusselt number
α	Heat convection coefficient, W/(m^{2}K)
λ	Heat conduction coefficient, W/(mK)
c_p	Spesific heat capacity, J/(kgK)
t	Time, s
L	thickness, m
l	Conveyor tape length, m
$\dot{V}$	Volume flow rate of air, m^3/s
e	Napiershe Logarithmus

Indices, sub or super

A	miscible (here solvent)
B	miscible (here air)
o	origin
∞	infinite (here oven atmosphere)
i	centre, axis of symmetry
J	constant

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