



# Development of Hot Air Dryer Conveyor for Automotive Tampo Printing Parts

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**ABSTRACT:** This paper presents the development of a hot air dryer conveyor for the automotive industry in the tampo printing part of the process. The research started by designing and creating the actual device that is ready to use and be implemented in the industry. The method provided details on the drying chamber, hot air dryer, and their mathematical model. The chosen hot air dryer operated in the factory default of auto-tuning mode. The performance evaluation studies indicated the performance of the hot air dryer for the chosen size of the drying chamber, the robustness of the system against fluctuating environmental air change rate, the ducting capacity, and the damper opening value estimation performance. The result of this system was working well at the specification requirement of operating at an air change rate of 15 to 21 while working at 80% of its maximum capacity, and the equipment has been successfully implemented. The detailed results are that the conveyor is only working while the settled temperature was achieved and the full work sensor is off, the hot air dryer perfectly matches the chamber size, and the chamber size selection was also well calculated and implemented.

**KEYWORDS:** Hot air dryer; drying chamber; tampo printing; conveyor; automotive

## 1. Introduction

Tampo printing is a printing technique using silicon tampons to transfer the ink to the surface. Tampo print is usually used in printing where it is difficult to print because of complexity, surface texture, or geometry [1]. In the automotive industry, after the tampo printing process, the paint needs to be treated because it's still wet and not penetrating well to the printing surface. If it's not handled properly, it will cause a defect on the products. Several drying techniques have been proposed. Hebbar et al. proposed the development of a combined infrared and hot air dryer for vegetables [2]. Mwithiga and Olwal presented the drying kinetics of kale (*Brassica oleracea*) in a convective hot air dryer [3]. Zhou et al. presented drying technology in the field of machining [4]. Satpati et al. proposed a pneumatic conveying dryer, while Siyu et al. proposed drying for fungus [5-7]. Mathioulakis et al. proposed a simulation of air movement in a dryer by computational fluid dynamics: an application for the drying of fruits, where the air movement inside the drying chamber was simulated using computational fluid dynamics (CFD), and Wankhade et al. presented the drying characteristics of okra slices on

drying in a hot air dryer [8-9]. The objective of this research was to develop a hot air dryer conveyor for automotive tampo printing parts that is robust and adaptable to the fluctuating environment from 15 to 21 % of the air change rate. The rest of this paper is outlined as follows: Section 2 talks about the development of the dryer and describes the details of how to design, develop, and implement the proposed method. Section 3 describes the studies that indicated the performance evaluation of the hot air dryer, the robustness of the system against fluctuating environmental air change rate, the ducting capacity, and the damper opening value estimation.

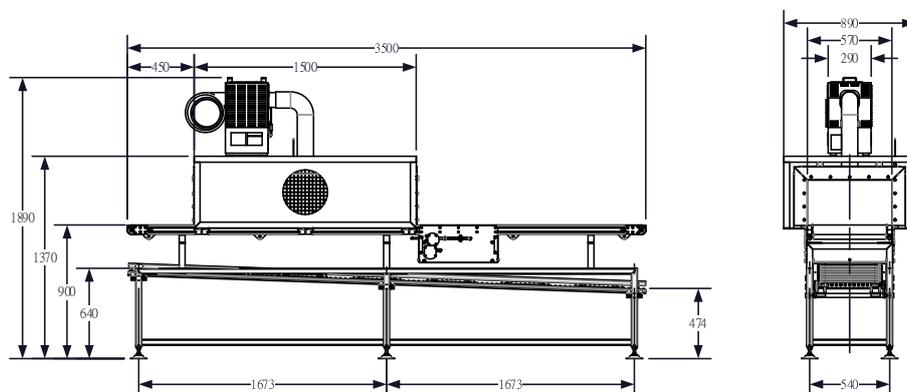
## 2. Development of Dryer

### 2.1. Specification requirement

The machine design was carried out in order to dry the wet paint of the small-sized plastic in the automotive part following the tampo print process. The width and height of the part vary from 30 to 150 mm. During the drying process, the parts will be placed on a plate that can hold 10 to 50 parts, depending on the part size. The plate size is 300 mm x 470 mm and the part shape is also varied. The plastic material's base color is black, and the paint is white. Inside the chamber, the required drying temperature is stable at 60–85 °C with clean hot air that is free of dirt. The drying time is constant and controllable by speed control at 10–15 minutes for one cycle process. The conveyor will run only when the temperature range is achieved. The conveyor will be stopped and enter standby mode while the full work sensor is ON and the weekly timer is added for the automatic starting of the machine in the morning. Also, the portability of the equipment for easy and fast replacement, easy maintenance, and no heat outside the equipment means safety when accidentally touching the cover, which is also required.

### 2.2. Hot air dryer conveyor general assembly

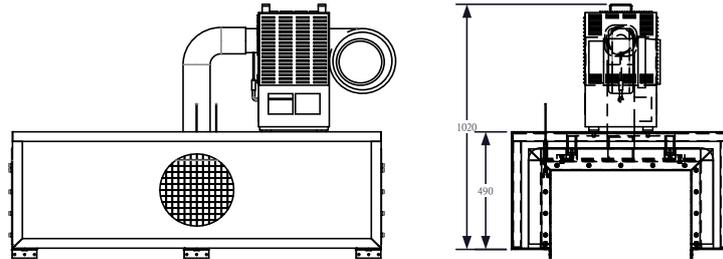
The continuous blow from the hot air dryer combined with the controlled semi-continuous belt conveyor has been developed for drying the wet paint on the plastic automotive parts. Figure 1 depicts the representation of the hot air dryer conveyor with an overall dimension of 890 mm (W) x 3500 mm (L) x 1890 mm (H).



**Figure 1.** Design of hot air dryer conveyor assembly

### 2.3. Drying chamber

The drying chamber is an area of heating with an outer dimension of 890 mm (W) x 1500 mm (L) x 490 mm (H) and an inner dimension of 570 mm (W) x 1500 mm (L) x 200 mm (H). Figure 2 depicts a detailed view of the heating chamber. The heating chambers are provided with mirror polished stainless steel for maximum heat radiation and are equipped with heat isolation material on the outer layer of the chamber body to make the outer chamber temperature cooler than the inside, so whenever they are unconsciously touched, they will not burn a hand.

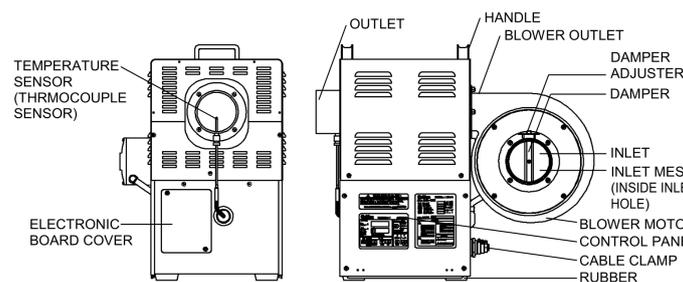


**Figure 2.** Design of drying chamber

The heat insulation material used for this equipment is Rockwool. Rockwool has the characteristic of isolating heat emitted by the hot air dryer and the outer layer of the chamber. The aluminum foil wrapped with wire mesh is installed on the outer layer of the chamber. This is to wrap the rockwool and prevent the deformation of the rockwool.

### 2.4. Hot air dryer

The hot air dryer is the equipment used to produce hot air before distributing it into the heating chamber. The required hot air for this system is adaptable control and clean hot air without any subdued flying and sticking on the wet part. Figure 3 depicts the representation of the hot air dryer.



**Figure 3.** Hot air dryer [10]

The selected hot air dryer is the SHD-9F II from Suiden Japan. The reasons for choosing this hot air dryer are its portability and ease of operation. This equipment also produces clean hot air with ease and does not require heavy maintenance. It is easy to change whenever there is a failure during the operation, and finally, it is easy to replace. For more details about the full specification of the chosen hot air dryer equipment, please refer to [10]. The hot air dryer type selection follows the chamber size, maximum air change rate on the area of installation, and adding an error compensation as a safety factor [11,12]. Equation 1 shows the mathematical model to get the chamber volume [13].

$$V = W L H \quad (1)$$

Where  $V$  is the volume of the chamber ( $m^3$ ),  $W$ ,  $L$ ,  $H$  is the width, length, and height of the inner chamber. After getting the chamber volume, the needed air volume per minute should be obtained following Equation 2.

$$V_R = V ACR \quad (2)$$

The range of air change rate (ACR) on the machine installation area is between 15 to 21. Following Equation (3), and working at 80% of its maximum capacity then add the error compensation on needed air volume per minute, then the dryer capacity can be carried out.

$$\text{Dryer Capacity} = V_R + \text{Error compensation} \quad (3)$$

With the settled error compensation is 10%, the dryer capacity ( $m^3/\text{min}$ ) value will be compared with the market size hot air dryer to get the best size and capacity of the hot air dryer that will be used for this work.

$$\text{Ducting Capacity} = V_F A \quad (4)$$

After obtaining the dryer capacity, the ducting capacity should also be obtained. Ducting is used to transmit the hot air produced from the hot air dryer to the heating chamber. Following Equation (4), the ducting capacity can be obtained. To obtain the ducting capacity, the flow velocity and the area of the ducting should be calculated [12]. Equation (5) is declared to get the flow velocity inside the duct.

$$V_F = C * \sqrt{\frac{(2 * P_W * G_c)}{\rho}} \quad (5)$$

Where,  $V_F$  is flow velocity (FPM),  $P_W$  is the velocity pressure (inches  $H_2O$ ),  $\rho$  is the density of air ( $lbm/ft^3$ ),  $G_c$  is the gravitational constant ( $32.174 lb_m * ft/lb_f s^2$ ) and  $C$  is the unit conversion factor (to feet and from in  $H_2O$ ) = 136.8 [11,12]. Table 1 shows the environmental density of the air due to the elevation height.

**Table 1.** Air density elevation value

No	Elevation (ft)	Density ( $lb./ft^3$ )
1	0	0.0745
2	500	0.0732
3	1000	0.0719
4	1500	0.0706
5	2000	0.0693
6	2500	0.0680
7	3000	0.0668
8	3500	0.0656
9	4000	0.0644
10	4500	0.0632
11	5000	0.0620
12	7500	0.0564

After getting the flow velocity, the unit needs to be converted from FPM to  $\text{m}^3/\text{min}$ . The cross-sectional area of the duct is obtained by the multiplication of the mathematical constant of  $\pi$  and the radius of the duct [13].

$$A = \pi r^2 \quad (6)$$

The ducting capacity should be larger than the hot air dryer's capacity. The hot air dryer capacity is also affected by the opening percentage of the damper. The damper is used to control the inlet air, so the amount of air blown out from the hot air dryer can be adjusted. Following Equation (7), the damper opening capacity can be found by multiplying the airflow capacity and the percentage of the damper opening that is open at the same time.

$$DOC = \frac{\text{Damper opening (\%)}}{100} U_{ERR} \quad (7)$$

Where  $DOC$  or damper opening capacity ( $\text{m}^3/\text{min}$ ) and  $U_{ERR}$  are the maximum airflow capacity from the hot air dryer in 80% of operating capacity. Figure 4 depicts the hot air damper.

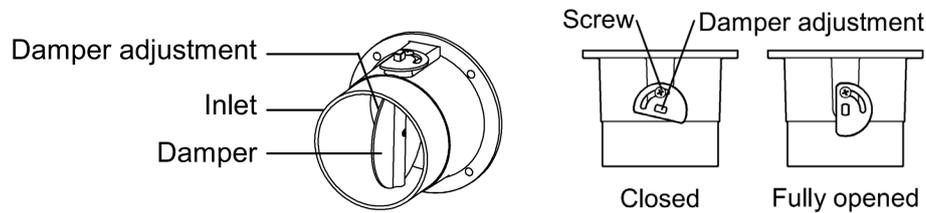


Figure 4. Hot air dryer damper [10]

### 3. Performance Evaluations

#### 3.1. The hot air dryer performance evaluation

The hot air dryer's performance is aligned with the size of the heating chamber. The larger size of the heating chamber required a higher performance dryer. Assume that we have a chamber with an inner dimension of 570 mm (W) x 1500 mm (L) x 200 mm (H) with the required air change rate maximum at 21, following the equations (1) and (2), the result is shown in Table 2.

Table 2. Hot air dryer capacity [10]

Dryer Type	Max Air Velocity ( $\text{m}^3/\text{min}$ )	80% of the capacity ( $\text{m}^3/\text{min}$ )
SHD- 1.3FII	1.7	1.36
SHD- 2FII	2.1	1.68
SHD- 4FII	3.7	2.96
SHD- 6FII	4.3	3.44
<b>SHD- 9FII</b>	<b>5.0</b>	<b>4.0</b>
SHD-15FIII	8.0	6.4

Set the hot air dryer running at 80% of its maximum capacity, then add a safety factor or error compensation to the needed air volume per minute. Following equation (3), we get that the dryer capacity should apply air at not less than  $3.9501 \text{ m}^3/\text{min}$ . Finally, we chose SHD-9F II

with a maximum air velocity of 5 m<sup>3</sup>/min, which is the nearest higher point for dryer capacity at 4 m<sup>3</sup>/min.

### 3.2. The system robustness for unstable ACR

The system robustness for unstable air change rate is the ability of the selected hot air dryer to maintain the output keep stable even there are changes in the environment. Using equation (3) and setting the hot air dryer to work at 80% of its maximum capacity for error compensation, the result is shown in Table 3.

**Table 3.** Outflow capacity against air change rate

Air Change Rate	Required Outflow Capacity (m <sup>3</sup> /min)	Result
15	2.8215	Good
16	3.0096	Good
17	3.1977	Good
18	3.3858	Good
19	3.5739	Good
20	3.762	Good
21	3.9501	Good
22	4.1382	Not Good
23	4.3263	Not Good

The machine's effectiveness in terms of environmental change is excellent as long as the air change rate is equal to or less than 21. The lower the required outflow capacity values, the more efficiently this machine operates.

### 3.3. The ducting capacity performance

The hot air was transferred from the hot air dryer to the chamber via ducting. To calculate the duct capacity for carrying the air blow, the diameter and elevation of the duct must be determined. The diameter of the round ducting is 100 mm (radius = 50 mm) at an elevation of less than 500 feet. According to equation (6), the capacity of the ducting is 286.84 CFM or 8.0316 m<sup>3</sup>/min. When we compare the hot air dryer's maximum capacity of 5 m<sup>3</sup>/min to the duct capacity, we see that the dryer capacity is less than the duct capacity, indicating that the duct size is appropriate. This duct is more than adequate to serve as a conduit for the hot air distribution.

**Table 4.** Duct size and its capacity

Duct Size (mm)	Ducting Capacity (m <sup>3</sup> /min)
40	1.285
60	2.891
<b>80</b>	<b>5.14</b>
<b>100</b>	<b>8.031</b>
<b>120</b>	<b>11.565</b>
140	15.742
160	20.56

According to Table 4, the ideal ducting capacity for the current hot air dryer is between 80mm and 120mm or radius 40 to 60. The diameter of the ducting used on this machine is 100mm.

### 3.4. Damper opening value performance

The damper opening value performance is the way to get the minimum opening of the damper. Following Equation (7), the result is shown in Table 5 below. With the hot air dryer setting capacity at 80%, the damper opening should not be below 70% for the ACR 15 because at ACR 15, the outflow capacity is 2.8215 m<sup>3</sup>/min compared to 70% opening only provide 2.8 m<sup>3</sup>/min.

**Table 5.** Damper opening performance

Damper Opening (%)	Out Flow Capacity (m <sup>3</sup> /min)
10	0.4
20	0.8
30	1.2
40	1.6
50	2
60	2.4
70	2.8
80	3.2
90	3.6
100	4

## 4. Conclusion

A continuous conveyor equipped with a hot air dryer chamber has been successfully applied and has proven to be robust in the face of fluctuating air change rates. This paper discusses the dryer's development, including how to choose a hot air dryer, chamber size, ducting size calculation, and damper opening calculation. The performance evaluation studies determined the hot air dryer's performance for the selected drying chamber size, the system's robustness against fluctuating ambient air change rates, ducting capacity, and damper opening value estimation performance. As a result, this system was operating at the specified air change rate of 15 to 21, and the equipment has been installed successfully. The detailed results indicated that the conveyor operates only when the settled temperature is reached and the full work sensor was turned off, that the hot air dryer was sized perfectly for the chamber, and that the chamber size selection was also well calculated and implemented. The lower the required outflow capacity values, the more efficiently this machine operates.

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