Development of an Energy-Efficient Machining Chip Dryer for Enhanced Metal Recycling

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Abstract. This study presents the design, analysis, and optimization of a machining chip dryer tailored for industrial environments generating substantial quantities of metal chips during turning, milling, and drilling operations. These chips are often saturated with cutting fluids such as oil or coolant, rendering them hazardous and unsuitable for direct recycling or disposal. Improperly dried chips contribute to storage challenges, corrosion, unpleasant odours, slippery work surfaces, and potential fire risks. Moreover, moisture-laden chips degrade the quality of recycled metal and elevate environmental concerns. The proposed dryer integrates three core components: a centrifugal air blower delivering hot air, a temperature-controlled heating chamber, and a conveyor mechanism ensuring uniform chip movement and consistent drying. Critical process parameters—including airflow rate, drying temperature, and conveyor speed—are optimized for enhanced performance. Computational Fluid Dynamics (CFD) is employed to model the airflow and heat distribution within the system, ensuring even thermal exposure. Response Surface Methodology (RSM) facilitates experimental design and process optimization, while Analysis of Variance (ANOVA) identifies the most influential variables. The resulting system significantly improves drying efficiency, promotes effective chip recycling, reduces energy consumption, and enhances operational safety.

Keywords: Machining chip dryer, Air flow rate, Temperature, Blower and Conveyor Specifications, 3D CAD model.

1. Introduction

Machining processes are fundamental to modern manufacturing, shaping raw materials into precise components. However, these processes generate substantial quantities of metallic waste known as swarf or machining chips. These chips are often contaminated with cutting fluids and lubricants, which pose serious environmental and safety concerns if not properly treated. Improper disposal, such as in landfills, risks soil and water contamination. Furthermore, wet chips are difficult to handle and store, occupying more volume and increasing the likelihood of workplace hazards like slips and potential fire incidents due to flammable oils. Effective chip drying is, therefore, crucial—not only for environmental compliance and operational safety but also to enhance recyclability and reduce waste management costs.[1] Below Fig (1) shows chip formation process. Drying efficiency is directly influenced by machining parameters such as tool geometry, feed rate, and material properties. Studies show that higher rake angles generate thinner chips with increased surface area, improving drying rates, whereas lower rake angles and poor clearance can produce dense, heat-retaining chips that dry inefficiently. Feed rate also affects chip thickness; higher feed rates lead to larger chips that retain more coolant and require longer drying times. The nature of the workpiece material further influences drying behaviour—ductile materials produce uniform, heat-conductive chips that dry faster, while brittle or low-conductivity materials hinder heat transfer, reducing drying efficiency. Several researchers have explored complementary approaches to chip handling and drying. Thomas Kivevele et al. [1] highlighted the potential of heat pump drying systems (HPD) as energy-efficient and environmentally sustainable alternatives, especially for heat sensitive materials. Similarly, Shane Le Capitaine et al. [2] emphasized the role of chip dryers in secondary

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aluminium production, stating that modern rotary dryers are essential for hydrocarbon removal and efficient metal recovery. In another study, Prasetya et al. [3] demonstrated a 300% increase in productivity by integrating oil drying machines in chip manufacturing SMEs, validating the industrial value of such systems.

Fig. 1. Chip formation During Machining [1]

Moreover, insights from Mohd Fahrul Hassan et al. [4] into chip compacting technologies and the fluid dynamics simulations from I. Olaru [5] provide a foundation for optimizing airflow and heat transfer mechanisms in drying systems. These findings collectively underscore the need for a well-engineered, thermally efficient chip dryer. In response to these challenges and gaps, this research proposes the design and thermal-CFD analysis of a machining chip dryer system integrating centrifugal airflow, temperature control, and conveyor movement, aiming to achieve efficient fluid removal, material recovery, and industrial sustainability. Existing machining chip drying systems predominantly rely on thermal heating, centrifugal spinning, or vacuum-assisted mechanisms, which often result in high energy consumption, increased operational cost, and limited effectiveness for irregular or entangled metal chips. Thermal dryers, in particular, require substantial electrical or fuel input, while centrifugal dryers are less efficient for fine or mixed chip morphologies commonly generated in CNC machining. To address these limitations, the present study proposes an energy-efficient machining chip dryer based on a forced ambient-air drying concept, eliminating the need for external heating elements. Unlike conventional designs, the proposed system employs CFD-driven optimization of airflow parameters such as duct diameter, blower rotational speed, and air velocity to ensure uniform airflow distribution and effective moisture removal across the chip bed. Furthermore, the dryer is specifically designed as a pre-processing unit for metal recycling, enabling efficient removal of residual cutting fluids and moisture prior to remelting. This approach not only reduces energy consumption but also enhances material recovery efficiency, positioning the proposed dryer as a sustainable and scalable alternative to conventional chip drying systems.

The primary novel contribution of this study is the development of a non-thermal, energy-efficient machining chip dryer that utilizes CFD-optimized forced ambient airflow for effective moisture and coolant removal. Unlike conventional chip drying methods that depend on thermal heating or centrifugal separation, the proposed system eliminates external heat sources, thereby reducing energy consumption and operational cost. A systematic CFD-based approach is employed to optimize key design parameters, including duct diameter, blower rotational speed, and airflow velocity, ensuring uniform airflow penetration through the chip bed. Furthermore, the dryer is specifically designed as a pre-processing solution for metal recycling applications, enhancing chip cleanliness prior to remelting and contributing to sustainable manufacturing practices. This integrated design-and-analysis framework represents a distinct advancement over existing chip drying technologies.

2. Design Calculations for Machining Chip Dryer

The duct diameter, blower rotational speed, and air velocity were selected based on literature-guided preliminary design, industrial constraints, and CFD-based optimization. The duct diameter and blower RPM were initially estimated to deliver sufficient volumetric airflow with minimal pressure loss and power consumption, while the inlet air velocity was limited to ensure effective moisture removal without causing chip displacement. A parametric CFD analysis was then conducted to evaluate airflow uniformity, pressure drop, and turbulence characteristics, and the final parameters were chosen to achieve uniform airflow through the chip bed with energy-efficient operation.

The initial ranges for duct diameter, blower speed, and air velocity were guided by prior literature on forced-air drying systems and industrial airflow design. The final values were refined through CFD-based parametric analysis to match the specific drying chamber geometry and operational requirements of the proposed system.

Table 1. Design parameters for calculation

Parameter	Formula / Description	Calculations	Result
Area of Duct	$A = \frac{\pi}{4} d^2$	$\frac{\pi}{4}(0.14)^2$	**0.0153 m²**
Velocity of Air	$V = \frac{\pi \times D \times N}{60}$	$\frac{\pi \times 0.26 \times 1000}{60}$	**13.61 m/s**

Motor RPM	$N = \frac{60 \times 2F}{P}$	$\frac{60 \times 2 \times 50}{6}$	**1000 rpm**
Volumetric Flow	$Q = A \times V$	$0.0153 \times 14.13 \times 60$	**12.57 m³/min**

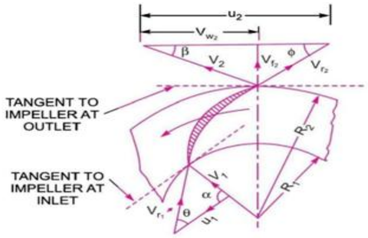

Fig. 2. Impeller Angle for Design Calculations [2]

3. Computer Aided Drafting of Drying Equipment

The computer-aided drafting (CAD) of the machining chip dryer, as illustrated in Figure 3, provides a comprehensive visualization of the system's structural and functional components. The detailed orthographic and isometric views offer clarity on dimensions, airflow pathways, and conveyor integration, ensuring precise assembly and fabrication. The CAD model enables accurate spatial planning, facilitates interference checks, and supports optimization of component layout before physical prototyping. Incorporating both sectional and external views, the drafting highlights essential design features such as blower placement, duct routing, and chip flow direction, confirming the system's readiness for manufacturing and implementation in industrial drying applications. The design is scalable through modular airflow units, though challenges related to airflow uniformity, pressure loss, and energy consumption must be addressed during large-scale implementation**.**

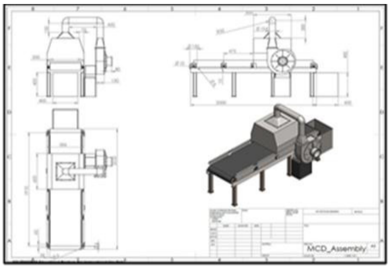

Fig. 3. Computer Aided Drafting of Drying Equipment

4. Computational Fluid Dynamics of Air Blower

4.1 Computational Fluid Dynamics of Air Blower with Flow Trajectories

The Computational Fluid Dynamics (CFD) analysis of the air blower, as shown in Figure 4, illustrates the velocity distribution and flow behaviour within the drying system. The simulation reveals a well-formed airflow path, with uniform velocity distribution reaching up to 13.61 m/s, validating the blower's capacity to effectively direct air through the drying chamber. The flow trajectories confirm minimal turbulence and optimized duct geometry, supporting efficient thermal transfer and chip drying. This analysis helps refine the blower design to ensure consistent airflow, energy efficiency, and effective separation of cutting fluids from machining chips under varying operational conditions.

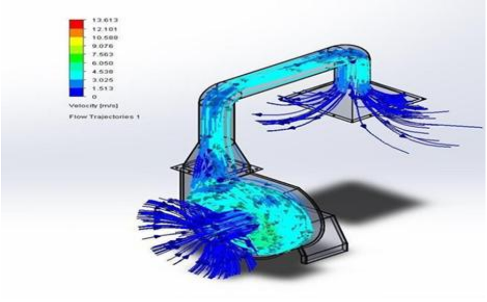

Fig. 4. Computational Fluid Dynamics of Air Blower with Flow Trajectories

4.2 Computational Fluid Dynamics of Air Blower with Transient Explorer

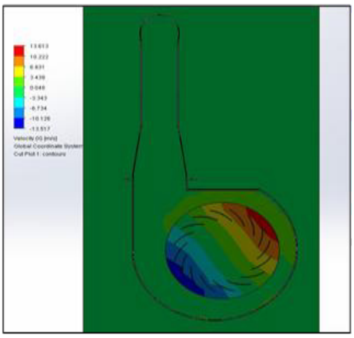

Fig. 5. Computational Fluid Dynamics of Air Blower with Transient Explorer

The Computational Fluid Dynamics (CFD) analysis using the Transient Explorer, as shown in Figure 5, provides valuable insight into the dynamic velocity distribution within the blower housing over time. The contour plot highlights areas of high and low airflow, with peak velocities reaching up to 13.61 m/s. This transient simulation captures unsteady flow behaviour, helping identify flow separation zones and ensuring consistent air movement critical for efficient chip drying. The results validate that the blower geometry supports stable and uniform velocity profiles during operation, which directly contributes to enhanced thermal transfer, reduced drying time, and improved overall system performance. A steady-state RANS approach with the standard k–ε turbulence model was used, employing velocity inlet and pressure outlet boundary conditions. Mesh independence was ensured, and convergence was achieved when residuals fell below 10^{-5} with stabilized flow variables.

5. Result Analysis of Computational Fluid Dynamics

To validate the theoretical calculations, a CFD analysis was performed using SolidWorks. The simulation accurately replicated internal flow conditions and revealed critical insights into airflow behaviour through flow trajectories and transient velocity contours. As shown in Figures 4 and 5, the maximum air velocity reached 13.61 m/s, which aligns closely with analytical predictions. The volumetric flow rate achieved was 12.57 m^3/min, as summarized in Table 2, confirming the design's effectiveness in delivering sufficient airflow for chip drying. These consistent results between analytical and CFD methods validate the accuracy of the theoretical model and the performance reliability of the air blower design. The study is currently limited to CFD-based evaluation; experimental or prototype-level validation is planned for future work to quantify airflow and drying performance.

Table 2. Design parameters and operating conditions used in the CFD simulations

Parameter	Result
Area of Duct	0.0153 m^2
Vel. of Air	13.61 m/s
Volumetric Flow	12.57 m^3/min

The drying performance of the proposed system is primarily governed by airflow interaction with the chip bed rather than material thermal conductivity, as the dryer operates using forced ambient-air convection without external heating. Consequently, variations in thermal conductivity among common machining materials have a limited influence, while chip morphology plays a dominant role, with fragmented chips allowing better airflow penetration than long or entangled chips. The CFD-optimized airflow distribution mitigates these effects, indicating applicability across different chip materials, with future work focused on experimental validation of material-specific performance.

6. Conclusion and Future scope

The design and analysis of the machining chip dryer effectively addressed key challenges in chip drying within manufacturing environments. By optimizing parameters such as airflow rate, temperature, and conveyor speed, the system ensures efficient fluid removal and supports sustainable recycling of metal waste. The integration of a belt conveyor, air blower, and heating chamber enhances thermal efficiency while minimizing energy loss. CFD analysis validated structural integrity and uniform airflow distribution, ensuring consistent drying performance. Tailored for small to mid-scale operations, the developed system offers a cost-effective, energy-efficient, and environmentally responsible solution for industrial chip management. The present study is limited to CFD-based analysis and does not include full-scale experimental validation of drying performance. Moreover, the current design focuses on non-thermal airflow-based drying without considering hybrid thermal optimization or adaptive control strategies. Future work will involve prototype development and experimental testing to quantify drying efficiency and energy consumption, investigation of thermal enhancement using low-grade or waste heat sources, and implementation of real-time process control through sensor-based monitoring and feedback control to accommodate varying chip materials and operating conditions.

References

1. T. Kivevele, Z. Huan, A review on opportunities for the development of heat pump drying systems in South Africa. S. Afr. J. Sci. 110(5), 1–11 (2013)
2. D. Prasetya, I. N. G. Wardana, I. G. N. A. Putra, Increasing the productivity of chips manufacturers through utilization of chip raw materials chopper and oil drying machine. IOP Conf. Ser.: Mater. Sci. Eng. 288, 012046 (2017)
3. M. Hassan, A. Arifin, A. Ismail, M. Ibrahim, Design and development of a portable metal chip baler using a system design approach. MATEC Web Conf. 135, 00018 (2017)
4. I. Olaru, A study of the cooling systems and fluid flow simulation in metal cutting processing. IOP Conf. Ser.: Mater. Sci. Eng. 227(1), 012009 (2017)
5. T. Albrecht, X. Thiem, L. Penter, S. Ihlenfeldt, Effects of hot chips in dry cutting processes on the temperature field and displacement of the machine table of machine tools. J. Mach. Eng. 19(3), 31–42 (2019)
6. M. F. Hassan, A. M. T. Arifin, A. E. Ismail, M. R. Ibrahim, Design and development of a portable metal chip baler using a system design approach. J. Eng. Appl. Sci. 3(5), 417–422 (2017)

7. S. Le Capitaine, Aluminum chip (swarf) dryer critical to many secondary aluminum operations. FEECO Int. Tech. Pap., 457–465 (2023)
8. Machining chip drying system illustration. Available online: https://images.app.goo.gl/uzS8XYdeWtpsNem9A (accessed 2024)