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Preventive Analysis of Polymer Leakage in Injection Molding Machines and Its Impact on Production Efficiency

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Abstract
This study examines the causes and impacts of polymer leakage in a 500-ton injection molding machine, which frequently occurs at the nozzle and sprue bushing junction. Leakage is caused by seal wear, excessive injection pressure, and nozzle misalignment, which enlarges microgaps. Measurements show that at a pressure of 150 MPa and a temperature of 250°C, the leakage rate reaches 20–100 ml/h. Through Autodesk Moldflow simulations, the nozzle-sprue transition area was identified as the point of maximum pressure (152 MPa) with the highest leakage potential, thereby extending conventional maintenance diagnostics through simulation-based identification of critical stress zones rather than relying solely on routine visual inspection. After optimizing the design and process parameters including reducing the injection pressure to 140 MPa, using heat-resistant Viton seals up to 250°C, and readjusting the nozzle position the leakage rate decreased by 70% (from 60 ml/h to 18 ml/h). The output of this study is a leak prevention model based on visual inspection, direct measurement, and numerical simulation, which distinguishes this work from standard industrial troubleshooting by integrating predictive simulation with quantitative cost-saving analysis, enabling an increase in production efficiency by ± 5 percent and operational cost savings of approximately US$1,800 per year per machine.

Keywords : Injection Molding, Polymer Leakage, Damage Analysis, Prevention, Plastic Manufacturing

Introduction

Injection molding is a plastic manufacturing process that involves injecting molten polymer into a mold under high pressure. An injection molding machine consists of key components such as a hopper, screw, heating cylinder, and hydraulic system. Polymer leaks can occur due to seal wear, excessive pressure, or design errors, and these conditions often lead to costly machine failures and production downtime. This process involves The injection of liquid or semi-liquid polymer into a mold at high pressure to form a product with high-precision shapes and dimensions. An injection molding machine generally consists of several main components: a hopper (raw material storage area), a screw, or feed screw. (which functions to melt and push the polymer), heating barrel or cylinder **,** nozzle , and hydraulic or servo system that regulates the injection pressure and speed.

Damage caused by polymer leaks is not just a technical issue but also has economic consequences. According to data from the Plastics Industry Association (2022), approximately 15% of injection molding machine failures globally are caused by polymer leaks. However, in its operation, polymer leakage **occurs .** often a significant problem. These leaks occur when the melted polymer material escapes from the normal flow path. usually around the nozzle, seal, or connection between components due to seal wear, overpressure, assembly errors, or design flaws in the injection system . In addition to causing technical problems, polymer leaks also cause material buildup on engine surfaces , increasing the risk of mechanical damage. And product contamination **.**

From an economic perspective, the impact is quite significant. According to a report from the Plastics Industry Association (2022) **,** approximately 15% of injection molding machine failures globally are caused by polymer leaks, with estimated annual losses reaching hundreds of millions of dollars due to production downtime, repair costs, and material waste. Furthermore, undetected leaks can cause damage to vital components such as heating cylinders and hydraulic systems , which are costly to replace.

This article aims to identify the main causes of polymer leakage in injection molding machines **,** analyze their technical and economic impacts **,** and presents solution steps that can be applied in the plastics manufacturing industry . The discussion will also be accompanied by a practical case study at an automotive component factory , where polymer leakage caused injection system failure during a continuous production cycle.

Through this analysis, it is hoped that a preventive approach can be found. such as selecting a seal material that is more heat resistant, injection pressure optimization **,** and application Real-time temperature and pressure monitoring system to minimize the risk of leakage and increase the operational efficiency of injection molding machines.

Literature review

Polymer leakage in injection molding machines has been discussed in various engineering literature and industry reports, which can be thematically grouped into studies focusing on mechanical wear, process instability, and maintenance-related failures rather than viewed as isolated technical observations. Most studies highlight that leakage occurs due to a combination of seal wear, elastomer material degradation, increased screw-barrel clearance, and injection pressures exceeding design limits, representing the dominant mechanical degradation mechanisms reported across different machine configurations. Seal failure is the dominant cause, as the elastomer undergoes thermal aging, friction, and chemical reactions with polymer additives, opening a path for melt to escape from the processing system, thereby linking material degradation processes with recurring leakage phenomena.

Several studies on screw and barrel wear have shown that the abrasiveness of certain polymers (e.g., polymers with mineral or glass fiber fillers) accelerates the growth of radial gaps, which reflects a recurring theme in the literature concerning mechanically induced clearance expansion. These gaps promote backflow and can develop into external leaks as process pressures increase. Modern injection molding process literature also emphasizes that unstable peak pressures can lead to sudden seal failure, highlighting process instability as a critical trigger that interacts with mechanical wear mechanisms.

The impacts of leaks documented in industry reports include hydraulic oil contamination, fluid channel blockages, corrosion due to chemical reactions between polymers or additives and metal components, and hydraulic actuator failure, which are commonly discussed as downstream system-level consequences of unresolved leakage events. Oil contamination is listed as a leading cause of hydraulic system failure in molding machines, where polymer particles harden to form varnish, which inhibits valve movement and reduces injection performance.

As mitigation measures, the literature recommends preventive maintenance such as periodic seal replacement, real-time pressure and temperature monitoring, oil analysis to detect early contamination, and the use of high-temperature and reactive sealing materials (e.g., PTFE or fluoroelastomers), largely positioning maintenance as a reactive or condition-based response to leakage symptoms. Polymer flow simulation (CAE/Moldflow) is also widely used to predict leak risk points in machine and mold designs, although its integration with economic impact assessment remains limited in prior studies.

In general, previous studies agree that polymer leakage is a multidimensional problem influenced by mechanical design, process parameters, and material conditions, yet most investigations address these dimensions separately, so prevention must combine process control, proper material selection, and a consistent maintenance program, which forms the basis for the present study's integrated approach that synthesizes simulation-based diagnostics with operational and economic evaluation.

Method

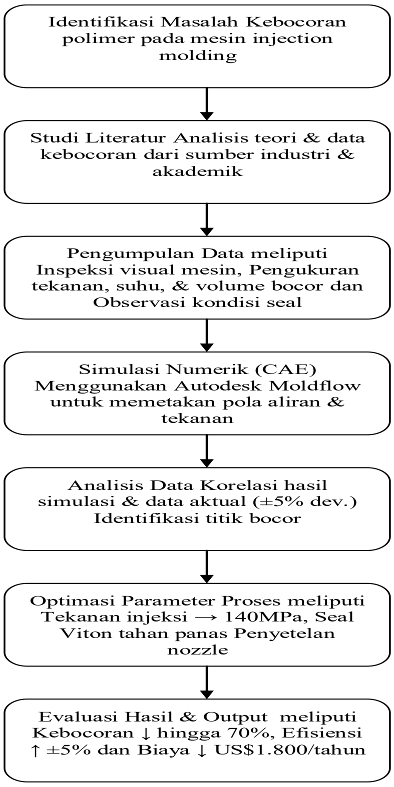

Figure 1. Flowchart

Moldflow simulation results were validated through correlation analysis between actual data and software predictions, with a maximum deviation tolerance of ± 5% . Furthermore, the interpreted results were presented in the form of pressure–temperature graphs , polymer flow maps , and economic analysis to assess the effectiveness of leak prevention measures.

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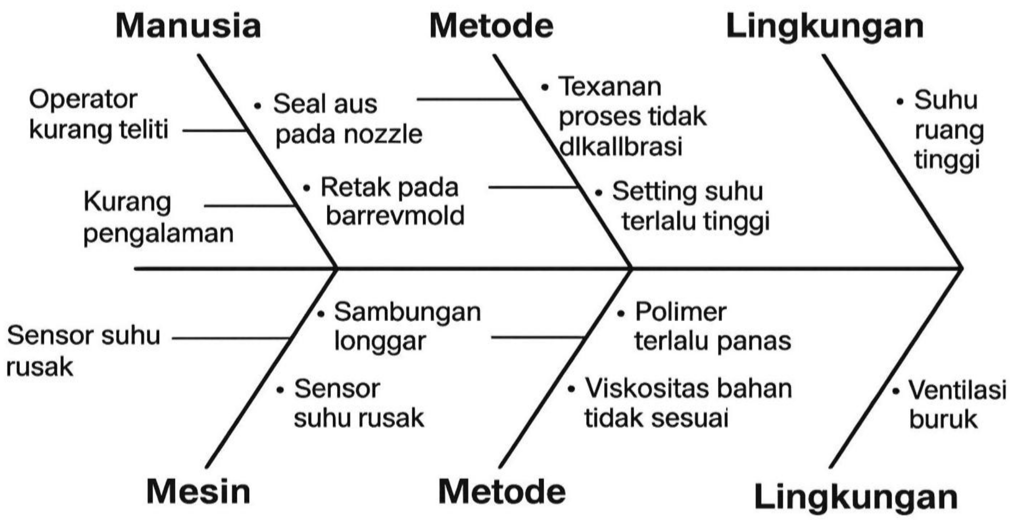

Figure 2. Possible causes of polymer leakage in injection molding machines

Results and Discussion

The results of this study confirm that excessive injection pressure and thermal degradation of the seal are the dominant causes of ABS polymer leakage. Moldflow simulation has proven effective in identifying maximum pressure points and leak patterns, enabling it to be used as a predictive tool in injection system redesign. Implementing preventive measures based on simulation data has yielded significant results in reducing leak rates, extending component life, and improving production efficiency.

Inspection results on a 500-ton injection molding machine model showed that polymer leakage occurred in the nozzle connection area. Sprue bushing. Liquid ABS polymer was detected leaking at a rate varying between 20–100 ml/hour. depends injection pressure. Measurements show:

- Actual injection pressure: 150 MPa
- Liquid polymer temperature: 250°C
- Nozzle position deviation: 0.25 mm from the mold axis
- Seal condition: shows wear and micro-cracking after 500 simulated production cycles .

Figure 3. Injection Pressure Diagram

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The following line graph shows the relationship between injection pressure and polymer leakage rate in an injection molding machine. It can be seen that when the injection pressure is reduced from 150 MPa to 140 MPa, the polymer leakage rate is significantly reduced from about 60 ml/h to 18 ml/h , indicating the effectiveness of process parameter optimization.

The analysis results showed that polymer leakage originated from a combination of problems with the operator, machine, process method, and work environment.
The main factors identified:

a) The operator was less careful and less experienced, so that inspection of the condition of the nozzle, barrel, and process parameters was less than optimal.
b) Engine components are worn or damaged, especially nozzle seals, loose connections, and inaccurate temperature sensors.
c) Uncalibrated process methods, including excessively high temperature settings and the use of materials with inappropriate viscosities.
d) Hot environments and poor ventilation, cause the polymer to easily become too liquid and increase internal pressure.

Leaks occur due to temperature and pressure instability triggered by component damage, process setting errors, and unfavorable environmental conditions.
Core recommendations :
1. Seal replacement and joint repair.
2. Routine calibration of sensors and process parameters.
3. Operator training for better visual and technical control.
4. Improve ventilation and room temperature control.

FAKTOR PENYEBAB	KETERANGAN MASALAH	DAMPAK	SOLUSI TEKNIS / PENYELESAIAN
Operator	- Operator kurang teliti & kurang berpengalama-nan. - Inspeksi kondisi nozzle, barrel, dan parameter proses tidak optimal.	- Pengaturan proses tidak konsisten. - Potensi keboc-oran mening	- Berirkan pelatihan operator secara rutin. - Ganti `SOP inspeksi háriarian (nozzle, barrel, temperature setting). - Usur cheaıclanayentskenlari
Komponen Mesin	- Komponen aus atau ru-sak. Sesn - Seal nozzele longgar. - Sambungan ném. - Sensor subu tidak akura-	- Kebocoran dari area sambungan - ketidaksta-bilan tekanan pengarutan	- Ganti seal nozzle yang sudah aus. - Periksa kekencangan sambun-gan secara periodik. - Kalibrasi sensor suhu seca tanɔ preentive maintenane
Metode Proses	- Parameter proses tidak terkalibrasi. - Material material dengan viskositas	- Material ter-lulù menahaca pancer tenpeimkasi	- Perbalki ventilasi ruang prodù-ksi. - Tambahikan syentindigin IAC industri

Figure 4. Leakage Analysis Table on Injection Machines and Solutions

Figure 5. Polymer leakage in the injection molding machine


Figure 6. Repair core insert molding

Molding Repair Steps The following are the detailed steps that technicians usually carry out:
1. Welding / Build-Up
If there are any cracked parts or eroded material, do the following:

- TIG welding or laser welding to rebuild worn areas.
- After that the area is re-machined until it is close to the original size.

2. Machining / Refitting Repair with:
   - Milling , grinding, EDM to restore the shape and tolerances to the original design.
3. Detailed Inspection:
   - Checking surface flatness.
   - Measuring wear on core & cavity.
   - Check ejector pin, bushing, guide pin, and alignment location.

Figure 7. repair cavity insert molding

1. Cleaning (Total Cleaning)
   - Clean rust with rust remover or degreaser fluid.
   - Cleaning the cooling channel (cooling channel flushing).
   - Removes plastic, oil and coolant residue.
2. Polishing
   If the cavity surface is scratched or dull, a polishing process is carried out.
   - Stoning
   - S and paper finishing
   - P lishing diamond paste to restore surface smoothness.
3. Replacement
   Worn components are replaced, such as:
   - ejector pins
   - guide pins
   - bushings
   - springs
   - cooling fittings
4. Preventive Maintenance
   After repair, the mold is usually given:
   - anti-rust lubricant
   - cavity protective oil

- routine maintenance schedule

5. Consequences if Not Repaired

If the mold in the photo is not repaired, potential problems include:

- Defective molded products (flash, short shot, warpage)
- Cycle time increases
- Mold is stuck or difficult to close
- Greater risk of damage and increased repair costs

Figure 8 Product results in molding

Molding is a production method used to shape raw materials, such as plastic or metal, into products of specific shapes and sizes using rigid molds. A variety of products can be produced using various molding techniques, such as injection molding, blow molding, and rotational molding.

Here are some examples of common products resulting from the molding process:

- Automotive Components : Many vehicle parts are made by molding, including dashboards, airbag covers, light brackets, mudguards and fuel tanks.
- Containers and Packaging: Various types of containers, such as plastic bottles, water gallons, jerry cans, buckets, jars, and cooler boxes, are mass-produced using molding techniques.
- Electronics and Medical Goods: Small components such as charging cases, control buttons, syringes, and medical vial containers are often manufactured with high precision through molding.
- Household Products and Toys: Children's toys, household furniture, and sporting equipment such as kayaks and canoes are also common products of the molding process.

The molding process enables efficient mass production with high consistency of shape and size for each product .

Conclusion

This study confirms that ABS polymer leakage in a 500-ton injection molding machine primarily occurs at the nozzle–sprue connection due to excessive injection pressure and high operating temperature. Moldflow simulation identified this area as the main stress concentration zone, with peak pressure reaching 152 MPa, validating its critical role in leakage initiation. Optimization of process and design parameters, including injection pressure reduction, the application of heat-resistant Viton seals, and precise nozzle realignment, successfully reduced leakage by up to 70% and improved production efficiency by approximately 5%. The integration of visual inspection, direct measurement, and numerical simulation demonstrates an effective and predictive approach for leakage detection and prevention beyond routine maintenance practices.

From an implementation perspective, regular inspection of the nozzle–sprue interface is essential for early detection of seal wear and misalignment. The use of high-temperature-resistant sealing materials such as Viton or PTFE, combined with periodic Moldflow simulation following process or design changes, is strongly recommended to anticipate leakage risks. Accurate nozzle alignment and continuous recording of pressure, temperature, and leakage data are critical to improving system reliability and sustaining operational efficiency.

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