

# Thermal and flow optimization and generative design simulations of the curing press manifold used in tire production

Ahmet Çağrı Çağlıyan<sup>1</sup>, Fikret Akyüz<sup>2</sup>, Ahmet Feyzioglu<sup>3</sup>, Sezgin Ersoy<sup>4</sup>

<sup>1,2</sup>FESTO San. ve Ticaret A.Ş., Aydınlı İYAYOSB Mahallesi Üniversite Caddesi Numara: 45, 34953 Tuzla, İstanbul, Türkiye

<sup>3</sup>University of Chester, Faculty of Science, Business and Enterprise, Chester, United Kingdom

<sup>3,4</sup>Advanced Research in Mechatronics and Artificial Intelligence, Marmara University, Istanbul, Türkiye

<sup>4</sup>Institute of Microtechnology (IMT), Technische Universität Braunschweig, Alte Salzdahlumer Str. 203, 38124, Braunschweig, Germany

<sup>4</sup>Corresponding author

**E-mail:** <sup>1</sup>ahmetcagri.cagliyan@festo.com, <sup>2</sup>fikret.akyuz@festo.com.tr, <sup>3a</sup>feyzioğlu@chester.ac.uk, <sup>4</sup>ersoy@marmara.edu.tr

Received 18 October 2024; accepted 29 November 2024; published online 30 November 2024  
DOI <https://doi.org/10.21595/jmai.2024.24625>



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**Abstract.** The tire industry involves complex processes that require high temperatures and pressures for tire production and processing. In these processes, rubber dough is placed in molds using baking presses and shaped under high temperature and pressure. Manifold blocks are used to feed the molds in these presses and to ensure equal temperature distribution between the molds. However, existing manifold blocks tend to deform in a short time under high temperature and pressure and require constant maintenance. These changes can affect production continuity, reduce production quality and increase maintenance costs. Therefore, there was a need to research a more durable and low-maintenance manifold solution. In this study, Thermal Flow analysis was performed on the Cooking Press Manifold using the “Generative Design” method and the appropriate operating level of the system was determined.

**Keywords:** thermal optimization, flow optimization, tire production, curing press.

## 1. Introduction

The global tire market is a sector that constantly develops demand due to the increase in the number of vehicles and the increase in travel times [1]. This development makes competition increasingly complex [2]. Tire manufacturers need end-to-end solutions they can use to optimize the availability of their facilities, reduce overall operating costs, and improve time to market [3-6]. Mechatronic system design and new business models introduced by digitalization help in improving these processes [7-12].

Tire is a product name and is a compound consisting of natural rubber, synthetic rubber, carbon black and oil [13-14]. Here, rubber, which is a natural material and produced from the rubber tree, has a volumetric size of around 80 % [15, 16]. However, synthetic rubber can also be produced in Europe [17, 18]. It can be defined as a rubber matrix structure. The remaining ingredients constitute the supplement part. Tires get their black color from Carbon and this additive is called Carbon black. Oil is used as another additive. Oil is used as a plasticizer [19-21]. In the production of the tire, the mixture is heated at 120 °C. The duration of this heating process and the type of rubber are selected according to the intended use of the tire [22].

Diversification of tires according to their intended use depends on production recipes [23, 24]. Production methods are as important a factor as components in the production of tires [25]. When the components are placed on the drum in the assembly lines, they begin to take shape on the surface of the stretching machine. Pressure is applied to the component placed on the loading wheel of the machine and the tire appears. Vulcanization method is applied in the shaping process

[26]. The rubber is taken to the hardening unit and the shaping process is completed with high steam pressure [27]. In determining the quality of the tire [28, 29], the material content [30] as well as the precision and control in the production process have an important impact.

The manifold structure developed in the study is a device used to give the final shape to the tires to be produced by applying pressure. Tire production for all transportation vehicles is carried out using similar systems. Tires produced with this system can be used in air, land and even sea vehicles. Automation in the production system can be improved or transformed depending on the green tire standard (tire structure before product state). A production system suitable for the intended use of the tire should be developed. In addition, this developed production system is a determinant of tire quality as well as tire type [31].

Tire curing presses can be operated individually or jointly depending on developing production technologies. These presses have a long column design that uses a locking and clamping system according to the desired features [32]. Although we have special designs, we can focus on 2 types of presses: mechanical tire curing press and hydraulic tire curing press. The mechanical press, which keeps the mold closed through articulated connections, is more preferred due to its easy maintenance. However, there are hydraulic presses in which hydraulic oil is used for the movement of the machine. Hydraulic presses secure the mold with a wedge lock mechanism [5, 33].

The aim of this study is to examine the performance of the system that controls the effect of high temperature and pressure in the pressing method used in the final stage of tire production and to redesign the geometry in the flow part of the manifold with productive design.

## 2. Method

As the process temperature increases, instability and complexity in thermal behaviour may be observed. This may have an effect that makes it difficult to control the production system. By placing the tire compounds into the molds, the system reaches high pressure and temperature values. Proper production of the product requires maintaining equal temperature in the manifolds. Otherwise, deterioration and deformation will occur in the products, which will cause losses such as cost, resources, time and processing time as faulty production. Maintenance costs arise when the system is stressed. In this study, a design that is durable and requires less maintenance in the production line has been put forward to eliminate the mentioned problems.

In the study, the optimum operating level of the system was determined by performing Thermal Flow analysis on the Cooking Press Manifold using the Generative Design method. Finite element analysis was used to achieve the targeted results in the study.

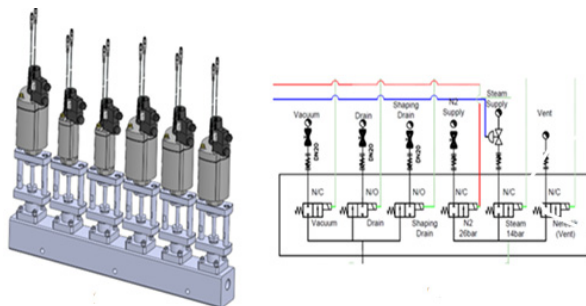


Fig. 1. CAD model and pneumatic diagram of the baking press manifold system

## 3. Results

### 3.1. System flow analysis

The behavior affecting the flow analysis of the system is based on the system being cooked

with rubber water vapour on the manifold and cooled with nitrogen gas. The system cooks the semi-finished tire with water vapour at 230 °C under 14 bar and cools it with nitrogen under 26 bar pressure, reducing the temperature to 25 °C. In this study, the flow analyses of different materials used in these two different processes in the developed system, under different pressures, were examined in order to keep the variable pressure and temperature values of the system stable. Different analyses were made for pressure and temperature effects in flow analyses. For these analyses, the volumes with flow were investigated in the CAD model and volume regions were created for two different analyses. (Fig. 2) Additionally, the temperature distribution under the temperatures applied to the tire baking press manifold was calculated using finite element analysis.

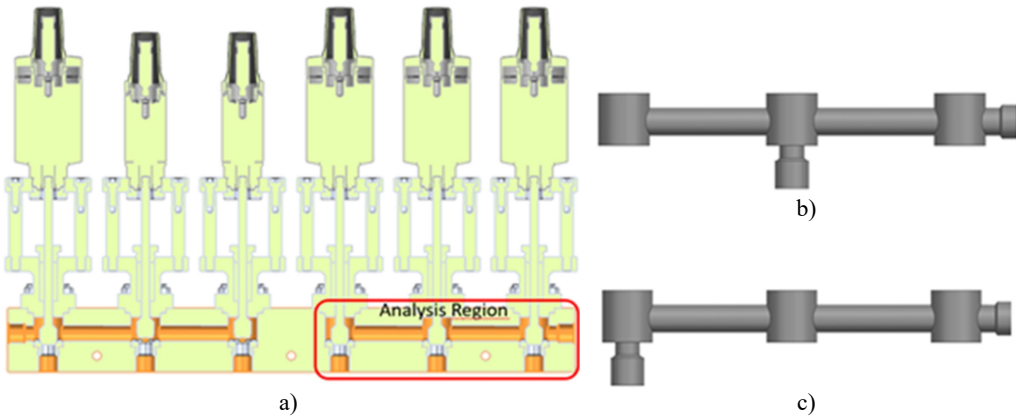


Fig. 2. Flow analysis study region to be analyzed flow (water vapor and nitrogen)

Finite element analysis values (FEA) were obtained in the case of two different scenarios in flow analyses, cooking with steam and cooling the tire with nitrogen.

In the flow analysis of water steam cooking process, the pressure measurements in the flow volume region and the flow velocity changes in the flow volume as a result of the flow analysis of water vapor under 26 bar are presented in Fig. 3. The pressure measurements of the Nitrogen gas used to cool the cured tire in the process and the flow rate changes.

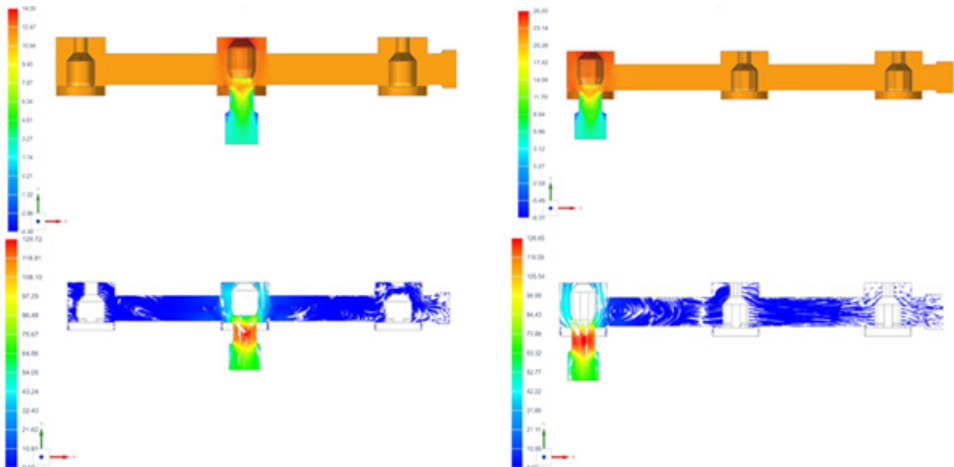


Fig. 3. Analysis results during flow analysis in the Tire Curing and Cooling process as pressure changes (bar) and flow rate changes (m/s)

Flow analysis results show that; It can be seen that the new manifold design we designed feeds the tire compound evenly. In this way, product quality and efficiency increased in the production

of tires. The same analysis method was applied to observe the temperature changes in the manifold part of the flow of the designed system. Thermal analysis results are seen in Fig. 4.

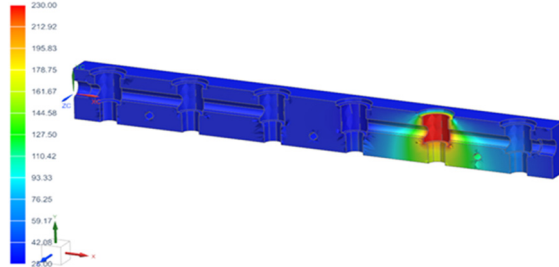


Fig. 4. Temperature distribution of the Tire Curing manifold during the process

### 3.2. Redesigning the flow path with generative design (GD)

This approach offers a different perspective from traditional design processes. It can automatically generate a large number of possible solutions to solve design problems.

While GM can increase the originality and innovativeness of the design, it can also improve the functionality, cost-effectiveness and performance of the design. At the same time, GD can be an effective tool to solve complex and difficult to optimize design problems. This approach offers designers the opportunity to explore solutions they might not have considered before and encourages creativity. It is especially used in areas such as product development, industrial design, architecture and engineering. This new approach can be used to solve design problems for fluids (such as liquids or gases). Such designs may often need to incorporate fluid dynamics, heat transfer, and similar physical phenomena. GD for fluids; It can be used in energy efficiency, fluid dynamics optimization, thermal design and many other areas. This approach can accelerate the design process to understand and optimize complex fluid behavior and help you achieve improved results. Thus, it helps optimize factors such as pressure and velocity in the gas flow. Thanks to automatic algorithms, different design options can be produced. It may be possible to increase energy efficiency and performance. It also offers more creative solutions by managing complex constraints. It accelerates the design process and ensures cost-performance balance.

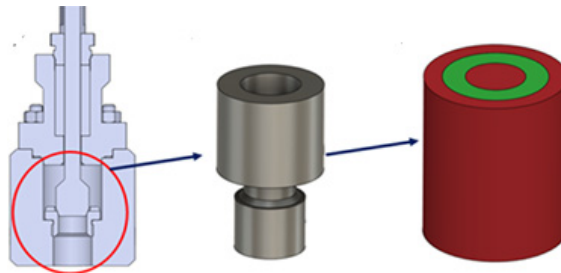


Fig. 5. Analysis of the flow region with GD

The accuracy of the model put forward in the analysis of the system with GD was investigated. For this reason, as in flow analysis, the geometry used by the fluid was created in the CAD environment as shown in Fig. 5. Some inputs of the model created with GD have been entered into the system (Fig. 5). In these inputs, as shown in the figure, the regions that should be in my model (green color) and the regions that I do not want to be in my model (red color) are defined. Regions where gas cannot circulate or have limited circulation are identified in red. It is the part where the physical quantities (pressure, flow rate, etc.) in the part where the flow occurs are defined. As a result of these inputs, artificial intelligence-supported flow analysis of the model was investigated.



Fig. 6. Analysis results and evaluation

The model presented as a result of the analysis shows that the conical structure in the outlet region of the piston cavity in the initial design should be redesigned. A model has been put forward in which it would be appropriate to create an accurate flow model in order to maintain the outlet diameter of the flow as a constant diameter. The velocity changes resulting from the flow analysis of the model put forward by GD are shown in Fig. 7. As a result of the analysis, it caused an increase in the flow rate in the proposed model compared to the primitive model.

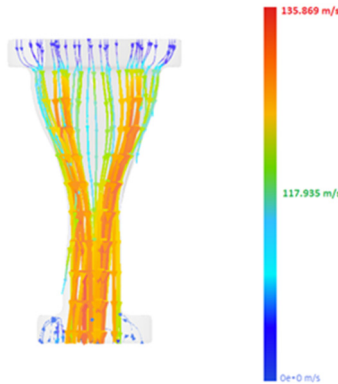


Fig. 7. Changes in flow velocity (m/s) of the model proposed by GD

#### 4. Conclusions

A new manifold solution that addresses the inadequacies of manifold blocks used in curing presses in the tire industry has been scientifically evaluated. This new solution offers an option that has a longer life, requires less maintenance and improves production quality. Flow and thermal analysis results also support the effectiveness of this new solution.

The model presented by GD to optimize the existing flow is a model proposed as a result of artificial intelligence-supported finite element study. It can be seen that the analysis results of this model can give better results than the first designed model.

These results show that the models put forward by GD contain a more complex geometry than their natural forms. In order to produce these models, production methods different from traditional production methods must be used. Although this situation seems to be a disadvantage of GM, there are rapid developments in production techniques and technologies. The GM method can produce better results for new generation manufacturing techniques such as additive manufacturing techniques.

In the flow analysis of the first design identified in the study, the suitability of the model is seen thanks to the negligibility of pressure change losses as a result of the formation of laminar flow and the opportunities provided by the production of the model with the classical method. We hope that this study and the design designed to solve this problem will contribute to the literature.

## Acknowledgements

The authors have not disclosed any funding.

## Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Author contributions

Ahmet Çağrı Çağlıyan: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, validation, visualization. Fikret Akyüz: conceptualization, project administration, software, supervision. Ahmet Feyzioğlu: resources, writing-original draft preparation, writing-review and editing. Sezgin Ersoy: conceptualization, resources, software, validation, writing-original draft preparation.

## Conflict of interest

The authors declare that they have no conflict of interest.

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**Ahmet Çağrı Çağlıyan** is a mechanical engineer. He graduated from Erciyes University in 2012. In 2013, he started his professional career and is currently working as a Project Manager at Festo A.Ş.



**Fikret Kemal Akyüz** in 1985 started his undergraduate education at Marmara University, Faculty of Technical Education, Department of Mechanics. After his Bachelor's degree, he started his Master's degree in 1990 and started his business life as a teacher. After working for 2 years, he received a scholarship from Baden-Württemberg state of Germany and received various technical trainings in Germany for 1 year. In 1997, he started working as a SW developer at Festo A.Ş. and currently continues to work as Customer Solutions Manager. He speaks English and German.



**Ahmet Feyzioğlu** received his B.Sc., M.Sc., and Ph.D. degrees in mechanical engineering from Marmara University. He also has a M.Sc. degree in industrial engineering from Middle East Technical University. His current research interests include mechanical design and production, system identification and control, and sustainability.



**Sezgin Ersoy** is an Professor of Mechatronics Engineering and Material Science. After graduating from Marmara University, he became a faculty member at the same university. His publications include a variety of efforts to understand changes in automotive mechatronics, polymer science and biomedical technologies. He is the editor and author of books. He has two science national awards and is an Editorial Member of several scientific journals.