PIJCU, Vol. 3, No. 2, June 2026
Page 01-08

Development and Field Implementation of BECOOL: A Forced-Air Agitated Post-Roasting Coffee Bean Cooling System for Micro-Roasteries

Lailatus Sa'diyah Yuniar Arifianti[1], Ferly Isnomo Abdi[2], Warju[3], Sudirman Rizki Ariyanto[4], Susi Tri Umaroh[5], Yustin Setiya Widoretno[6], Lutfi Setiawan Firmansyah[7]

[1,2,3,4,5,6,7] Universitas Negeri Surabaya, Surabaya, Indonesia

Keywords:
Coffee roasting
Forced air
Micro-roastery
Optimal Quality
Thermal reactions

ABSTRACT (9 pt)

Rapid cooling after coffee roasting is required to terminate residual thermal reactions and limit uncontrolled post-roast development. This study reports the development and field implementation of BECOOL (Bean Cooling System for Optimal Quality), an appropriate-technology cooling unit developed for Under Construction Roastery in Sidoarjo, Indonesia. The work followed an applied engineering development approach consisting of partner-needs assessment, CAD design, fabrication, internal running test, field installation, and operational evaluation. The fabricated system integrates a perforated stainless-steel cooling chamber, a rotating agitator, forced-air extraction through a blower and ducting path, and a 0.5 HP drive coupled to a WPX50 gearbox. The field record documents that the combined airflow and continuous agitation reduced hot post-roast beans toward room temperature in less than 3 min. Because continuous time-temperature logger data were not retained in the field report, the transient profile was not invented as an empirical result. Instead, a clearly identified first-order engineering reconstruction was performed using a conservative three-minute upper-bound scenario and a comparable literature boundary condition of 170°C to 35°C at 30°C ambient temperature. The reconstructed minimum cooling constant was 0.0185 s^{-1}. The results indicate that a locally fabricated forced-air and agitation architecture is technically feasible for micro-roastery post-roast handling, while repeated instrumented trials, airflow measurement, energy analysis, moisture/color testing, and sensory evaluation remain necessary for definitive quality-performance claims.

INTRODUCTION

Coffee roasting is a decisive thermal stage because changes in temperature and residence time determine the development of color, aroma, volatile compounds, and other physicochemical characteristics of the roasted bean. Recent studies show that roasting conditions significantly modify volatile profiles, including pyridines, furans, aldehydes, and other aroma-active compounds, demonstrating that thermal exposure must be controlled closely around the desired roast endpoint (Choe et al., 2023; Gancarz et al., 2022).

The end of heating does not immediately end thermal development. Roasted beans retain sensible heat and continue transferring heat within the bean bed after discharge from the roaster. For this reason, cooling is a functional part of roast control rather than a simple post-process handling step. Continued heat exposure can change volatile composition, while differences in roast degree also influence moisture, color, pH, and sensory attributes (Acquaticci et al., 2023; Muzaifa et al., 2024). A cooling system therefore needs to remove heat rapidly while keeping the bean bed sufficiently mixed to minimize localized hot spots.

Forced convection is a practical cooling strategy for small-scale coffee processing because it uses ambient air and can be integrated with a perforated cooling chamber. Nugroho et al. (2023) redesigned a blower coolant tray for a 1.5 kg coffee roaster using heat-transfer calculations and CFD, emphasizing blower selection, air suction, and ducting geometry. More recently, Harahap and Perangin-Angin (2026) developed a microcontroller-based forced-convection coffee cooling machine using temperature sensing and automatic blower control. These studies indicate that airflow architecture and temperature monitoring are important design variables, but they do not remove the need for mechanical mixing when the bean layer is relatively deep.

Under Construction Roastery in Gedangan, Sidoarjo, identified post-roast cooling as an operational limitation because its previous conventional method was considered insufficiently fast and uniform for planned production development. BECOOL was therefore designed as an appropriate-technology system with a nominal design target of up to 10 kg, combining a perforated cooling chamber, continuous mechanical agitation, and forced-air extraction. The design prioritizes locally available mechanical components so that operation, cleaning, and maintenance can be performed within a micro-roastery environment.

The objective of this study was to develop and implement the BECOOL post-roasting cooling system, describe its mechanical and airflow architecture, evaluate the field evidence retained during partner-site operation, and provide a transparent engineering reconstruction of the cooling transient where direct logger data were unavailable. The reconstruction is presented strictly as modeled data and is not treated as a substitute for unrecorded empirical measurements.

RESEARCH METHOD

This study used an applied engineering development and field-implementation approach at Under Construction Roastery, Gedangan, Sidoarjo, East Java, Indonesia. The work focused on developing an appropriate-technology system that could be fabricated with locally available mechanical components and integrated into the partner’s post-roasting workflow. The development process was conducted through five sequential stages: needs identification, engineering design, fabrication and assembly, internal running test, and field installation with operational evaluation.

Development Participants and Design Requirements

The development involved the university implementation team, student assistants, and the owner/operator of Under Construction Roastery as the field partner. The partner contributed information on the existing roasting and cooling workflow and provided the operating site for installation and trial use. The functional design requirements were rapid removal of heat after roasting, more uniform cooling through continuous bean movement, a nominal batch-capacity target of up to 10 kg, simple operation, ease of cleaning, and maintainability using commonly available mechanical components.

System Architecture and Fabrication

The cooling principle combined forced convection and mechanical agitation. Hot roasted beans were placed in a perforated stainless-steel chamber. A cross-arm agitator rotated through the bean bed so that beans were repeatedly repositioned and exposed to the cooling airflow. A blower extracted hot air downward through the perforated chamber base and directed it through the lower ducting path. The agitator was driven by a 0.5 HP electric motor coupled to a WPX50 reducer/gearbox to obtain lower-speed, higher-torque rotation suitable for mixing the bean bed. The frame and cooling chamber were fabricated from stainless-steel structural and sheet materials, followed by mechanical assembly, alignment, and an internal running test before field transfer.

Operational Evaluation and Data Analysis

Field evaluation used the evidence retained in the activity documentation: successful operation of the motor, gearbox, agitator, blower, and ducting system; installation at the partner site; operational use with hot post-roast coffee beans; and the recorded endpoint statement that the beans approached room temperature in less than 3 min. The retained report did not contain the exact batch mass used during the documented trial, the initial bean temperature, interval-by-interval logger data, air velocity, electrical power, bean moisture, color, or sensory scores. These variables were therefore not treated as measured observations.

To provide a quantitative thermal interpretation without fabricating experimental records, a separate first-order engineering reconstruction was calculated using Newton's cooling model, $T(t) = Ta + (T0 - Ta)e^{(-kt)}$. A starting temperature of 170°C and a target temperature of 35°C were adopted as comparable engineering boundary conditions from the Indonesian blower-cooling study of Nugroho et al. (2023), while ambient temperature was set at 30°C. The documented "less than 3 min" BECOOL endpoint was represented conservatively as 180 s. Solving the model produced $k = 0.01851\ s^{-1}$. Modeled temperatures were then calculated at 30 s intervals. All reconstructed values are labeled as modeled data and are not reported as direct BECOOL measurements.

RESULTS AND DISCUSSION

Development of the BECOOL System

The development process produced a compact cooling concept in which a circular cooling chamber is located above an enclosed structural frame. The chamber base is perforated to allow air to pass through the bean layer, while a centrally driven cross-arm agitator continuously moves the beans. This configuration separates the two main cooling functions: the blower provides convective heat removal, whereas the agitator reduces the probability that individual beans remain in local hot zones. The CAD configuration is shown in Figure 1.

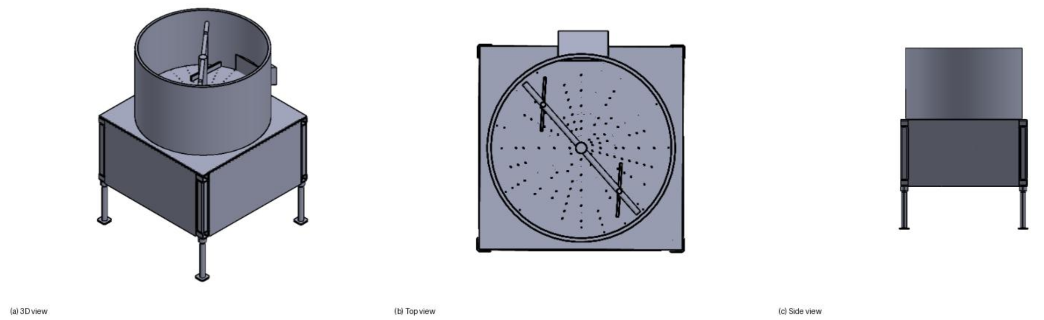

Figure 1. BECOOL CAD design: (a) 3D view, (b) top view, and (c) side view.

Fabrication records indicate that the principal drive system used a 0.5 HP motor with a WPX50 gearbox. The gearbox is important because direct motor speed is generally unsuitable for gentle bean-bed agitation; speed reduction increases available torque while limiting excessive bean movement. The blower and ducting system operate independently of the mechanical drive, creating an architecture that can be improved later by changing blower capacity, duct geometry, or agitator speed without redesigning the entire machine.

Table 1. BECOOL design architecture and evidence status

Subsystem	Documented configuration/function	Evidence status
Cooling chamber	Perforated stainless-steel chamber that allows hot air to be extracted through the bean bed.	Documented in design and fabrication records
Agitation mechanism	Rotating cross-arm agitator continuously turns the beans to improve exposure to cooling air.	Documented in fabrication and field-operation description
Air-cooling path	Blower-driven forced-air extraction with ducting beneath the chamber.	Documented in operating mechanism
Agitator drive	0.5 HP electric motor coupled to a WPX50 reducer/gearbox.	Documented in fabrication record
Batch capacity	Nominal design target up to 10 kg.	Design target; exact trial mass not retained
Cooling endpoint	Beans reported to approach room temperature in <3 min.	Documented field observation

Field Implementation at the Micro-Roastery

Following the internal running test, the BECOOL unit was transferred to Under Construction Roastery and integrated into the existing production space. Figure 2 shows the partner’s roasting environment and the roasted coffee handled during the activity. During operation, hot beans were placed into the cooling chamber, the agitator continuously changed their position, and the blower drew heated air downward through the perforated base. The simultaneous use of airflow and agitation is the central technical feature of BECOOL because the two mechanisms address different causes of slow or non-uniform cooling.

(a) Existing roasting workspace at the partner site

(b) Roasted coffee beans produced by the partner

Figure 2. Partner-site roasting environment and roasted coffee used during BECOOL implementation.

The project record reports that the combined airflow and agitation reduced the hot beans toward room temperature in less than 3 min. This endpoint is operationally promising for a micro-roastery, but it should be interpreted cautiously because the exact batch mass and starting temperature were not retained in the final report. Consequently, the documented result supports functional feasibility and rapid cooling behavior, but it does not yet support a mass-normalized cooling-rate comparison or a formal statistical claim.

Modeled Cooling Profile

Because continuous logger data were absent, the temperature curve shown in Figure 3 was reconstructed as an engineering scenario rather than created as fictitious experimental data. Under the selected upper-bound scenario, temperature falls from 170°C to 35°C in 180 s at an assumed ambient temperature of 30°C. The resulting first-order cooling constant is 0.01851 s−1. The steepest temperature decrease occurs during the early stage because the temperature difference between the beans and ambient air is largest at that time; the cooling rate then decreases as the bean temperature approaches ambient conditions.

Table 2. First-order engineering reconstruction of the three-minute upper-bound cooling scenario

Time (s)	Modeled bean temperature (°C)	Data status
0	170.0	Scenario boundary
30	110.3	Modeled
60	76.1	Modeled
90	56.5	Modeled
120	45.2	Modeled
150	38.7	Modeled
180	35.0	Scenario endpoint

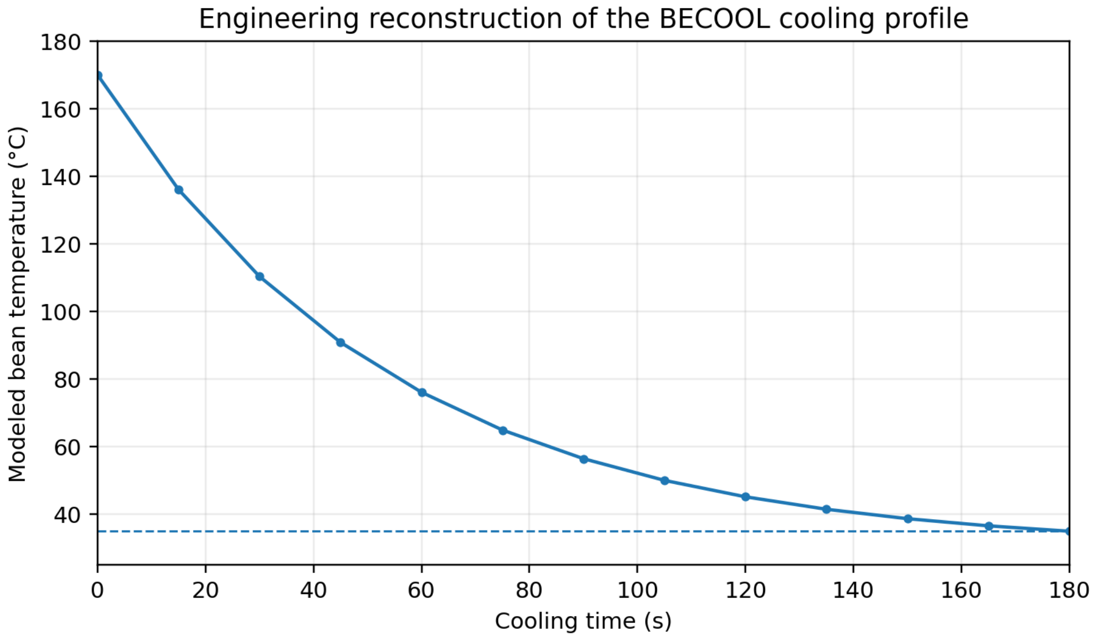

Figure 3. First-order engineering reconstruction of the BECOOL cooling profile. The curve is modeled, not a direct field logger trace.

Interpretation with Recent Coffee-Cooling and Roasting Studies

The BECOOL architecture is consistent with recent engineering work that uses forced convection to accelerate heat removal from roasted coffee. Nugroho et al. (2023) emphasized the importance of blower selection and ducting geometry in a coolant-tray redesign and reported a CFD air velocity of 2.359 m/s for their optimized configuration. Harahap and Perangin-Angin (2026) used forced convection with sensor-based blower control and demonstrated automated cooling to 35°C. These studies support the general use of airflow as the primary cooling mechanism, while BECOOL adds continuous mechanical agitation to improve exposure of the bean bed to that airflow.

Rapid termination of thermal exposure is also relevant to product quality because roasting conditions alter the composition of volatile compounds. Gancarz et al. (2022) showed that roasting technology influenced the volatile profile and pyridine content, whereas Choe et al. (2023) demonstrated that changing roasting time altered numerous aromatic compounds. Acquaticci et al. (2023) likewise found that coffee species, post-harvest treatment, and roast conditions affected compounds associated with quality and safety. These findings justify treating cooling as part of thermal process control; however, they do not prove that BECOOL itself improved aroma or cup quality because those outcomes were not measured in the retained field dataset.

The practical contribution of BECOOL is therefore best stated as a technology-development result. The system uses a chamber, agitator, motor-gearbox drive, blower, and ducting that can be fabricated and maintained using conventional workshop processes. This is relevant to micro-roasteries that may not be able to adopt high-cost industrial cooling systems. At the same time, the nominal 10 kg design target should be validated at known batch masses, because bed depth changes pressure drop, airflow distribution, mixing effectiveness, and cooling time.

Table 3. Contextual comparison with recent post-roast cooling studies

Source	Cooling concept	Reported information	Relevance to BECOOL
Nugroho et al. (2023)	Blower coolant-tray redesign	170→35°C engineering basis; CFD velocity 2.359 m/s; 1.5 kg roaster context.	Supports blower/ducting design importance; not directly comparable because BECOOL airflow was not measured.
Harahap & Perangin-Angin (2026)	Sensor-controlled forced convection	2 kg batch cooled to 35°C in 40 min from a 210°C roasting condition.	Shows automated forced-air cooling and temperature-based control as a current small-scale approach.
BECOOL field record	Forced-air extraction + mechanical agitation	Toward room temperature in <3 min; exact test mass and logger trace not retained.	Supports field feasibility; requires instrumented repeated trials before performance ranking.

Limitations and Validation Requirements

The principal limitation is the incompleteness of the retained quantitative performance record. The activity documentation preserved the less-than-three-minute endpoint statement but not the continuous temperature trace needed to estimate an empirical cooling constant, confidence interval, or between-batch variability. The exact mass of the documented field batch was also not retained. Therefore, the modeled curve in this paper must not be cited as measured BECOOL temperature data.

A follow-up validation should use at least three repeated batches at fixed and documented masses, preferably including several loads up to the 10 kg design target. Bean temperature should be logged at short, fixed intervals from roaster discharge until below 40°C. Ambient temperature, blower air velocity or volumetric flow, electrical power, agitator rotational speed, and total energy consumption should be recorded simultaneously. Physical quality can be evaluated through moisture and color, while standardized cupping or trained-panel testing can determine whether the cooling process produces measurable changes in aroma, sweetness, aftertaste, or overall sensory score. These additions would convert the present development case into a controlled performance study.

CONCLUSION

BECOOL was successfully developed and field-implemented as a forced-air, mechanically agitated post-roast cooling system for a micro-roastery in Sidoarjo. The system integrates a perforated stainless-steel cooling chamber, cross-arm agitator, blower and ducting path, and a 0.5 HP motor coupled to a WPX50 gearbox. The retained operational record reports that hot roasted beans approached room temperature in less than 3 min. A separate and explicitly labeled upper-bound engineering reconstruction produced a first-order cooling constant of 0.01851 s^{-1} for a 170°C-to-35°C scenario over 180 s. The study supports the technical feasibility of combining forced convection and continuous mixing in a locally fabricable cooling unit, but definitive claims regarding cooling capacity, energy efficiency, aroma preservation, or sensory improvement require repeated instrumented trials using known batch masses and recorded temperature, airflow, power, moisture, color, and sensory data.

ACKNOWLEDGEMENTS (OPTIONAL)
The authors acknowledge Universitas Negeri Surabaya for support through the Non-APBN community service program and thank Under Construction Roastery, Sidoarjo, for providing the field site and operational collaboration during development and implementation of BECOOL.

REFERENCES

Acquaticci, L., Angeloni, S., Cela, N., Galgano, F., Vittori, S., Caprioli, G., & Condelli, N. (2023). Impact of coffee species, post-harvesting treatments and roasting conditions on coffee quality and safety related compounds. *Food Control*, *149*, 109714. https://doi.org/10.1016/j.foodcont.2023.109714

Choe, W., Woo, J. H., Hong, M., Jang, H., Deepa, P., & Kim, S. (2023). Determination of aromatic profiles of coffee beans according to different roasting times by SPME/GC-MS analysis. *Journal of Applied Pharmaceutical Science*, *13*(10), 157–171. https://doi.org/10.7324/JAPS.2023.143318

Gancarz, M., Dobrzański, B., Jr., Malaga-Toboła, U., Tabor, S., Combrzyński, M., Ćwikła, D., Strobel, W. R., Oniszczuk, A., Karami, H., Darvishi, Y., Żytek, A., & Rusinek, R. (2022). Impact of coffee bean roasting on the content of pyridines determined by analysis of volatile organic compounds. *Molecules*, *27*(5), 1559. https://doi.org/10.3390/molecules27051559

Harahap, L. A., & Perangin-Angin, A. J. B. (2026). Micro controller based automated control system for coffee beans cooling machine. *IOP Conference Series: Earth and Environmental Science*, *1583*(1), 012026. https://doi.org/10.1088/1755-1315/1583/1/012026

Muzaifa, M., Setiawan, B., & Aunillah, A. (2024). Physicochemical and sensory qualities of Arabica coffee (Coffea arabica) obtained from different processing methods and roasting degrees. *International Journal of Agriculture and Biology*, *31*(3), 167–173. https://doi.org/10.17957/IJAB/15.2128

Nugroho, Y., Nugraha, A., Rozaq, A. A., & Pramudya, A. S. (2023). Re-desain sistem pendinginan biji kopi pada blower coolant tray mesin roasting kopi Pratter PT. Patmanunggal Reka Abadi. *Jurnal Kajian Teknik Mesin*, *8*(2), 36–46. https://doi.org/10.52447/jktm.v8i2.6767