Dynamic study of batch milk cooling process at KUD SAE Pujon

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Dynamic Study of Batch Milk Cooling Process at KUD SAE Pujon

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Abstract. The background of this research is to understand the operation process which is the overall main goal for developing the process model. This model is often used for operator training, process design, safety system analysis or design, or control system design. The dynamic model of milk cooling process from 36˚C to 4˚C using chilled water available at 2˚C were performed. Chilled water was maintained constant temperature by using refrigerant unit. The process being investigated was a Packo brand milk cooling tank belong to KUD SAE Pujon (Malang). A fundamental method using heat balance were used to derive the model, leading to a first order transfer function process in Laplace Transform. Transient simulation then could be done in order to investigate the dynamic behavior of the cooling process. The process is first order. For 2 hr cooling process (to achieve the goal) then the gain and time constant values are 1.00 and 42.3548 mins respectively.

Keywords: Laplace transfer function, simulation, dynamic study, batch cooling.

INTRODUCTION

Milk is a white liquid food that is rich in nutrients produced by mammalian milk glands [1]. This is the main source of nutrition for baby mammals, including human, before they can digest other types of food. Early lactation milk contains colostrum, which carries maternal antibodies to its young and can reduce the risk of many diseases. It contains many other nutrients including protein and lactose. Consumption of interspecies milk is common, particularly among humans, many of whom consume other mammalian milk.

Milk collection schemes differ from country to country and there is no single scheme that can be applied universally. Raw milk is a very perishable product that must be collected and cooled in the next few hours to reduce losses due to spoilage and to preserve quality. As milk production is often far from markets and processing facilities, in Indonesia the milk cooling center at Koperasi Unit Desa provide the means to maintain quality through chilling and hygienic storage before further transportation to processing facilities (milk factory)[2].

The cooling of raw fresh milk to below 4 °C as soon as possible after milking – and within three to four hours at the most - is recognized as the best way of preserving quality and avoiding spoilage. Therefore, it was done in Cooperatives (Koperasi unit Desa) as batch cooling process and this process are performed twice a day (in the morning and afternoon). However, in milk factory, milk cooling usually done in continuous process.

The main problem that often occurs in dairy factories is the operator's lack of understanding of the process that occurs. This creates difficulties in controlling the process or in designing appropriate equipment when needed.

The aim of this paper is to present the dynamic model of batch milk cooling process. The model in Laplace transform is important for controlling the process. Understanding the process operation is a major overall objective for developing a dynamic process model. This model is often used for operator training, process design, safety system analysis or design, or control system design [3].

Milk cooling is one of the largest consumers of electricity [4], therefore milk production is an energy intensive process. Milk can be cooled in two steps: precooling, followed by refrigerant cooling to 4°C. Cooling costs at a Milk

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Cooling Centers can be reduced by precooling the fresh warm milk using water from the mains supply or surface, well or groundwater. Precooling reduces the refrigeration load, thereby reducing costs and energy needs. When the temperature difference between the water and the fresh raw milk is significant, refrigeration costs can be reduced by up to 64 percent [2]. However, in tropical countries like Indonesia, normally we skip the first step since the temperature of water and fresh raw milk are about the same. The amount of energy needed for cooling depends mainly on the efficiency of the cooling system and the temperature difference in milk between the beginning and end of the cooling process [5].

Chilled water can be used to gradually cool the milk in the bulk tank. Water can be chilled using a water chiller or an ice bank equipment, which usually consists of an insulated water tank with an evaporator and a holding vessel. The water is chilled to approximately 2˚C and the milk is cooled to 4˚C. Another method of chilling water is by circulation through an ice bank. Ice builds up around the copper tubes in cylindrical formation. Water is circulated through the bulk tank and back to the ice bank in a closed loop [5].

When milk is stored above 30˚C, it can spoil after 4 h depending on its total bacteria count. Storing at 20˚C, 10˚C and 4˚C can partially inhibit the bacterial growth for the first 8, 16 and 24 h after milking respectively [6]

Murphy et. al. [5] studied feed forward and feedback controller for milk cooling system for two steps cooling (precooling and refrigerant cooling) and tuned using Ziegler Nichols ultimate gain method [7]. However, no information for the plant models were provided.

Coughanowr and LeBlanc [7] presented a fundamental method to obtain first order transfer function for mercury thermometer. In this paper, the method was adopted for derivation of milk cooling transfer function, which is similar in nature.

Investigations of waste heat recovery from bulk milk cooler [8] has also been conducted. Heat dissipated to atmosphere through condenser was recovered to improve the energy efficiency of the plant. The waste heat can be utilized to heat the water which was used to clean the milk processing equipment. Another modelling work but focuses on an ice bank for milk cooling after milking has also been performed [9]. Agustriyanto et.al [10,11] provided transfer function model for continuous milk cooling, while in this paper for batch cooling system.

Operators in dairy factories often do not understand the process that occurs, so they cannot control or design equipment according to their needs. This is a major problem in dairy factories.

The model addressed in this paper were based on fundamental theories or laws, such as the conservation of energy. Simulink were also used to simulate the model. Simulink is a block diagram environment for multidomain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with MATLAB, enabling us to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis. Therefore, it is easier for us to generate and analyze the data.

BATCH MILK COOLING PROCESS AT KUD SAE PUJON

The system being studied was the milk cooling facilities belong to Koperasi SAE Pujon as shown in Fig. 1. It is a rectangular milk cooling tank with a half cylinder tank contained therein. Rectangular tank as a place of cooling water, while the half cylinder tank as a container for milk. The scheme of the milk cooling tank is shown in Fig. 2.

List of notations:

V	=	Tank volume
T_1	=	Temperature of chilled water (˚C)
T_i	=	Temperature of inlet milk (˚C)
T_o	=	Temperature of milk inside the tank (˚C)
m	=	Mass of milk in the tank (kg)
C_p	=	Heat capacity of milk (kJ/kg.K)
A	=	Surface area of milk cooling tank (m2)
U	=	Overall heat transfer coefficient (kJ/kg)
ρ	=	Density of milk (kg/m3)
Q	=	Heat released from milk to cooling water (kJ/min)

FIGURE 1. Packo milk cooling tank (courtesy of Koperasi SAE Pujon)

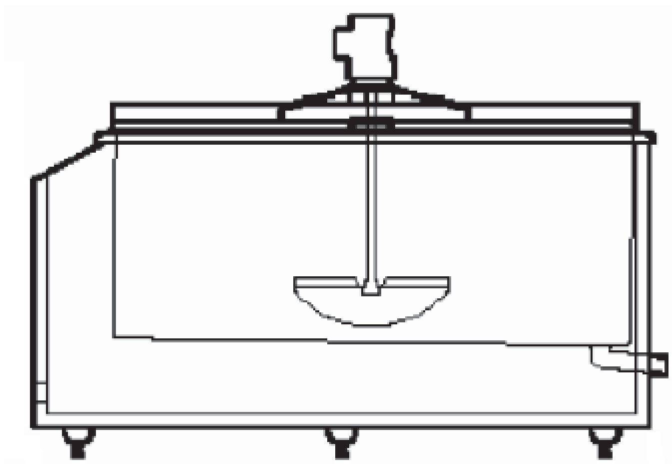

FIGURE 2. Stirred milk cooling tank system seen for the side (Courtesy of Koperasi SAE Pujon)

Table 1 shows steady state condition and parameter data for simulation.

TABLE 1. Steady state and parameter data

Parameters	Values	Units
V	2500	L
T_i	36	˚C
T_o	4	˚C
T_1	2	˚C
C_p	3.93	kJ/kg.K
ρ	1027	kg/m^3
m	2567.5	kg
U	274.4613	kJ/min.m^2.˚C
A	0.8680	m^2
Q	2690.74	kJ/min

The tank capacity (V) is 2500 L therefore the mass of milk in the tank can be calculated since the milk density is known. The volume of chilled water is unknown, but its temperature is kept constant at 2˚C (T_1) by using refrigerant. If we set the cooling time equal to 2 hours, then the total heat that must be released from milk to cooling water can be calculated as follows:

$$Q = m.C_p.\Delta T = 2567.5 \times 3.93 \times (36-4) \tag{1}$$

$$= 322.888.8 \quad kJ/2h$$

$$= 161444.4 \quad kJ/h$$

$$= 2690.74 \quad kJ/\min$$

Heat transfer area (A) is the area of half cylinder can be calculated mathematically, where $r = 0.3485m$ and $t = 1.238m$:

$$A = \frac{1}{2}.\pi.r(r+t) = 0.8680m^2 \tag{2}$$

Log mean temperature different (LMTD) for parallel flow then can be calculated [12] :

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} = \frac{(36-2)-(4-2)}{\ln\left(\frac{36-2}{4-2}\right)} = 11.2946 \tag{3}$$

Since $\quad Q = U.A.\Delta T_{LMTD}$ (4)

Then:

$$U = 274.4613 \text{ kJ/min.m2.˚C} \tag{5}$$

Batch milk cooling process can be modelled based on energy balance as follows [7]:

Unsteady state energy balance:

$$In - Out = Accumulation \tag{6}$$

$$Q_{in} - Q_{out} = Accumulation$$

When $Q_{in} = 0$, then:

$$0 - U.A.\Delta T = \frac{dQ}{dt}$$

$$-U.A.(T_o - T_1) = m.C_p \frac{dT_o}{dt}$$

$$U.A.(T_1 - T_o) = m.C_p \frac{dT_o}{dt} \tag{7}$$

Steady state energy balance:

$$U.A.(T_{1s} - T_{os}) = 0 \tag{8}$$

Equation (7)-(8):

$$U.A((T_1 - T_{1s}) - (T_o - T_{os})) = m.C_p \frac{dT_o}{dt} \tag{9}$$

Taking Laplace Transform of both sides in Equation (9):

$$U.A(T_1(s) - T_o(s)) = m.C_p.(sT_o(s) - T_o(0)) \tag{10}$$

When $T_o(0) = 0$, then:

$$U.A(T_1(s) - T_o(s)) = m.C_p.s.T_o(s)$$

$$T_1(s) = \frac{m.C_p}{U.A} s.T_o(s) + T_o(s)$$

$$T_1(s) = \left(\frac{m.C_p}{U.A} s + 1\right) T_o(s)$$

$$\frac{T_o(s)}{T_1(s)} = \frac{1}{\frac{m.C_p}{U.A} s + 1} \tag{11}$$

The resulting Equation (11) is a first order process transfer function [3] with:

Gain = $K_p = 1$ (12)

$$\text{Time constant} = \tau_p = \frac{m.C_p}{U.A} \quad (13)$$

RESULTS AND DISCUSSION

The milk cooling process in Cooperatives (Koperasi Unit Desa) is generally carried out as batch process. The batch process only depends on time. When the milk temperature has reached the expected, then the milk is released. Assume that the overall heat transfer coefficient (U) is constant, the result of the mathematical model according of Equation 11 is as follows:

$$\frac{T_o(s)}{T_1(s)} = \frac{1}{42.3548s+1}$$

From the mathematical model of the batch system above, the simulation results were shown in Fig. 3. Based on Fig. 3, it can be seen that the batch system only affects cooling time. The temperature of milk comes in at 36˚C and the temperature of milk reaches 4˚C with a cooling time of 120 minutes.

Since the gain is 1 while the time constant is 42.3548 minutes, the process will reach 2˚C at about more than 4 times the time constant. The time constant is the time required for the first-order process to reach 63.2% to the new steady state value when a step disturbance is given to the input variable.

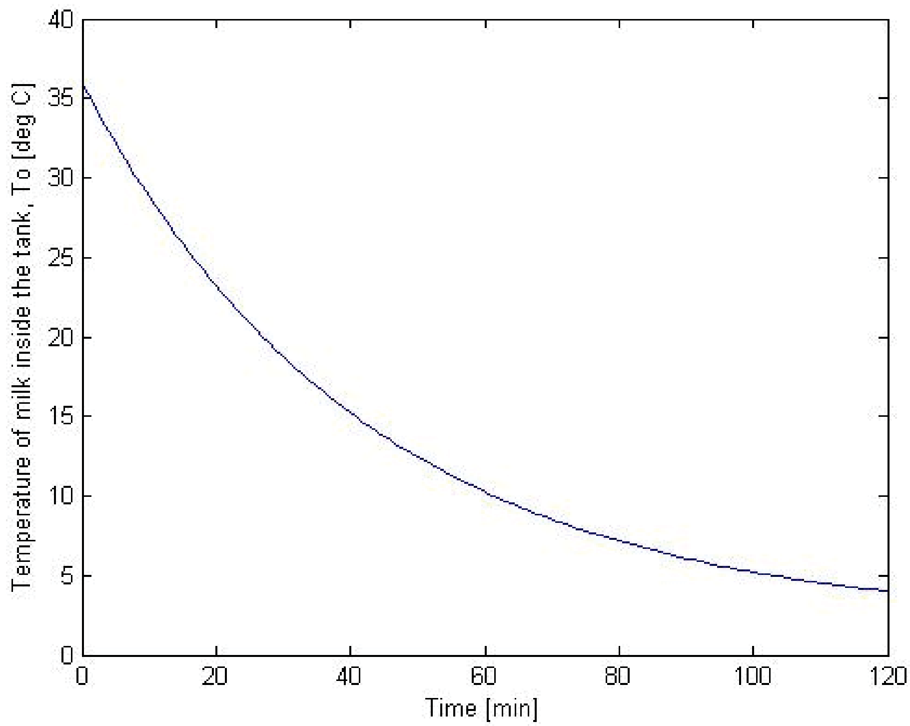

FIGURE 3. Milk temperature profile

Now, suppose that cooling water temperature varies as shown in Fig..4. The milk temperature profile in the tank can be investigated and shown in Fig. 5. Various results for different cooling water temperature can also be obtained easily using Simulink

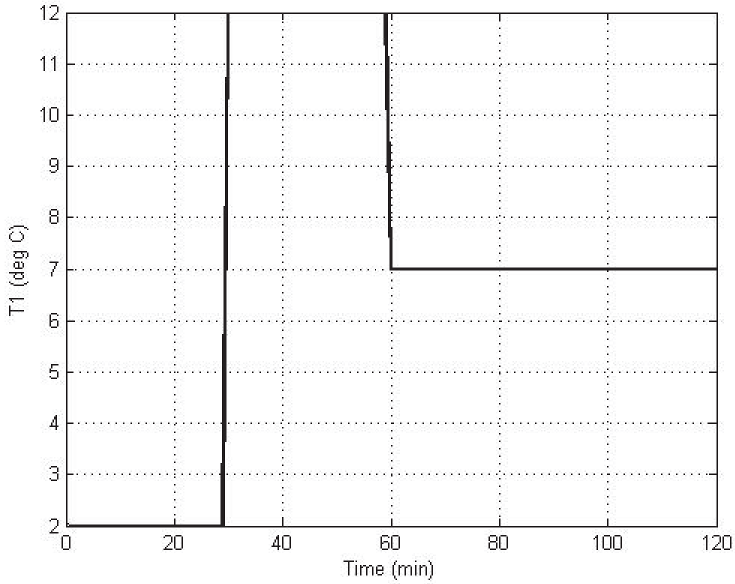

FIGURE 4. Temperature profile of inlet chilled water

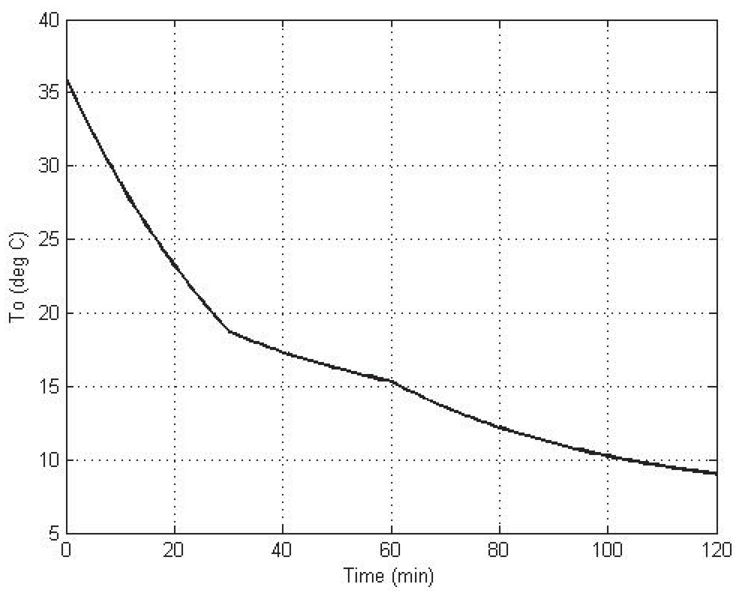

FIGURE 5. Temperature profile of milk

CONCLUSION

The result of the dynamic model is a first order transfer function as follows:

$$G(s) = \frac{T_o(s)}{T_1(s)} = \frac{1}{42.3548s + 1}$$

The dynamic model of batch milk cooling process has been simulated using Simulink. Overall heat transfer coefficient (U) was assumed to be constant and could be calculated as the batch process finish in 2 hours. The milk temperature profile shows reasonable dynamic during the process. The proposed model can be useful for control purposes.

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2503 (2022)

2668 (2022)

2653 (2022)

2455 (2022)

2451 (2022)

2657 (2022)

2676 (2022)

2661 (2022)

2524 (2022)

2519 (2022)

2640 (2022)

2515 (2022)

Table of Contents

PREV

NEXT

INTERNATIONAL CONFERENCE ON INFORMATICS, TECHNOLOGY, AND ENGINEERING 2021 (InCITE 2021): Leveraging Smart Engineering

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2518 (2022)
2522 (2022)
2632 (2022)
2696 (2022)
2663 (2022)
2573 (2022)
2633 (2022)
2533 (2022)
2551 (2022)
2478 (2022)
2529 (2022)
2528 (2022)
2505 (2022)
2550 (2022)
2636 (2022)
2449 (2022)
2520 (2022)
2656 (2022)
2610 (2022)
2460 (2022)
2487 (2022)
2434 (2022)
2472 (2022)
2638 (2022)
2570 (2022)
2461 (2022)
2437 (2022)
2559 (2022)

2021 (InCITE 2021)

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No Access . April 2022

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Yu-Chung Tsao, Felix Arril Simbara Barus and Chien-Wei Ho

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SHOW ABSTRACT

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Kansei engineering and product-service systems (KEPSS) integrative framework for customer-centered experience

Markus Hartono

AIP Conference Proceedings **2470**, 020002 (2022); https://doi.org/10.1063/5.0080177

SHOW ABSTRACT

No Access . April 2022

The role of supply chain performance factors to determine the firm performance

Yoni Kristiawan, Edi Purwanto and Rustono Farady Marta

AIP Conference Proceedings **2470**, 020003 (2022); https://doi.org/10.1063/5.0080235

2537 (2022)
2501 (2022)
2498 (2022)
2511 (2022)
2479 (2022)
2453 (2022)
2488 (2022)
2577 (2022)
2450 (2022)
2473 (2022)
2443 (2022)
2489 (2022)
2465 (2022)
2413 (2022)
2467 (2022)
2471 (2022)
2432 (2022)
2466 (2022)
2454 (2022)
2506 (2022)
2464 (2022)
2418 (2022)
2393 (2022)
2496 (2022)
2445 (2022)
2458 (2022)
2357 (2022)
2463 (2022)

SHOW ABSTRACT

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Real-time monitoring design for make-to-order industry

Senapati C. Adisasmito, Pradipta Deffinika Pamungkas and Anas Ma'ruf

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SHOW ABSTRACT

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Reducing production process lead time using Value Stream Mapping and Kaizen approaches: A case study in the musical instrument industry

Indra Setiawan and Hernadewita

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SHOW ABSTRACT

No Access . April 2022

Simple heuristics for scheduling apache airflow: A case study at PT. X

Hans Tanto, Indriati N. Bisono and Hanijanto Soewandi

AIP Conference Proceedings **2470**, 020006 (2022); https://doi.org/10.1063/5.0081042

SHOW ABSTRACT

No Access . April 2022

Quality improvement with PDCA approach and design of experiment method in single socks industry in Indonesia

2470 (2022)

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2383 (2022)
2509 (2022)
2425 (2022)
2459 (2022)
2405 (2022)
2444 (2022)
2391 (2022)
2469 (2022)
2424 (2022)
2435 (2022)
2474 (2022)
2390 (2022)
2430 (2022)
2440 (2022)
2462 (2022)
2456 (2022)
2386 (2022)
2421 (2022)
2385 (2022)
2384 (2021)
2442 (2021)
2412 (2021)
2409 (2021)

Hibarkah Kurnia, Choesnul Jaqin and Humiras Hardi Purba

AIP Conference Proceedings **2470**, 020007 (2022); https://doi.org/10.1063/5.0080179

SHOW ABSTRACT

No Access . April 2022

Integration of corporate social responsibility for improved company performance: Evidence from the Indonesian manufacturing industry

Esti Dwi Rinawiyanti, Xueli Huang and Sharif As-Saber

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SHOW ABSTRACT

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Community mobility during Covid-19 pandemic and tourism performance: Data mining approach

Gunawan

AIP Conference Proceedings **2470**, 020009 (2022); https://doi.org/10.1063/5.0080170

SHOW ABSTRACT

No Access . April 2022

Inventory system improvement for poultry

Noverta Brilly Leksana Putra, Indri Hapsari and Dina Natalia Prayogo

AIP Conference Proceedings **2470**, 020010 (2022); https://doi.org/10.1063/5.0080160

SHOW ABSTRACT

2448 (2021)
2403 (2021)
2407 (2021)
2363 (2021)
2441 (2021)
2388 (2021)
2423 (2021)
2402 (2021)
2381 (2021)
2372 (2021)
2338 (2021)
2420 (2021)
2416 (2021)
2411 (2021)
2429 (2021)
2428 (2021)
2387 (2021)
2419 (2021)
2410 (2021)
2401 (2021)
2438 (2021)
2447 (2021)
2408 (2021)
2417 (2021)
2395 (2021)
2439 (2021)
2404 (2021)
2375 (2021)

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Users' perception of digital prototypes in Indonesian fashion industry: A qualitative study

Christabel Parung and Prayogo Waluyo

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Recent advances and application of Selective Laser Melting (SLM) technology in the aerospace industry

Anel Yerubayeva, Essam Shehab and Md. Hazrat Ali

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2396 (2021)
2360 (2021)
2377 (2021)
2389 (2021)
2376 (2021)
2364 (2021)
2422 (2021)
2406 (2021)
2397 (2021)
2369 (2021)
2366 (2021)
2370 (2021)
2382 (2021)
2352 (2021)
2373 (2021)
2358 (2021)
2392 (2021)
2374 (2021)
2347 (2021)
2365 (2021)
2371 (2021)
2379 (2021)
2378 (2021)
2368 (2021)
2361 (2021)
2380 (2021)
2349 (2021)
2359 (2021)

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Immobilization of xylanase on acid pretreatment bentonite as green biocatalyst

Lieke Riadi, Ruth Chrisnasari, Joshua Kristanto, Cahaya Caesar Bigravida and Meyta Sanoe

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Rheological behavior and antioxidant activity of carrageenan extracted from Green seaweed (*Eucheuma cottonii*) using alkaline solution at low temperature

Puguh Setyopratomo and Lanny Sapei

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Elieser Tarigan

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Rice husk ash for the stabilization of the outer interfacial layer of W/O/W double emulsion

2362 (2021)
2356 (2021)
2367 (2021)
2353 (2021)
2351 (2021)
2341 (2021)
2355 (2021)
2339 (2021)
2348 (2021)
2350 (2021)
2345 (2021)
2342 (2021)
2340 (2021)
2331 (2021)
2343 (2021)
2346 (2021)
2336 (2021)
2344 (2021)
2335 (2021)
2337 (2021)
2333 (2021)
2323 (2021)
2328 (2021)
2334 (2021)
2330 (2021)
2320 (2021)
2332 (2021)
2329 (2021)

Lanny Sapei, Rudy Agustriyanto, Endang Wahyu Fitriani, Zerravym Levy and Cindy Sumampouw

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Putu Doddy Sutrisna, Meyta Sanoe, Rifando Gogo Adiyaksa, Kristina Wahyu Agustine, Hadiyatni Rita Priyantini, Prayogo Widyastoto Waluyo and I. Made Ronyastra

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2321 (2021)
2318 (2021)
2316 (2021)
2327 (2021)
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A performance study of magnetite-lignin composites as photothermal materials in solar steam generation system

Marta Devega Yuharma, W. Widiyastuti, Ni Made Intan Putri Suari and Heru Setyawan

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Organosolv lignin from coconut coir as potential biomaterials for sunscreen

Diana Novita Sari, Mahardika F. Rois, W. Widiyastuti and Heru Setyawan

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One-step electrochemical synthesis of silica-coated magnetite nanofluids

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Synthesis and characterization of chitosan-Allium sativum film

Emma Savitri, Maria Irine Tjahayani and Anastasia Apriyani Ngene Say

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2289 (2020)
2293 (2020)
2305 (2020)
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2261 (2020)
2275 (2020)
2271 (2020)
2264 (2020)
2267 (2020)
2262 (2020)
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Hate speech content detection system on Twitter using K-nearest neighbor method

Vincentius Riandaru Prasetyo and Anton Hendrik Samudra

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School finder, intelligent recommendation system for elementary school selection

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Designing a recommender system based on the application of decision tree algorithm in data mining with KNIME (for recommending the topic of undergraduate's thesis)

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2242 (2020)
2224 (2020)
2240 (2020)
2239 (2020)
2236 (2020)
2234 (2020)
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2186 (2019)

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2185 (2019)
2183 (2019)
2174 (2019)
2184 (2019)
2177 (2019)
2179 (2019)
2178 (2019)
2189 (2019)
2181 (2019)
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2158 (2019)

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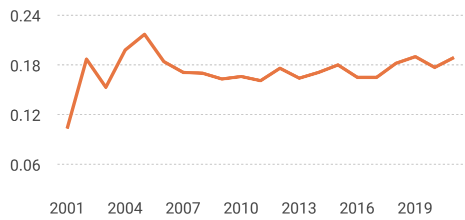

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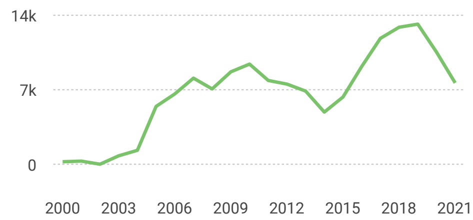

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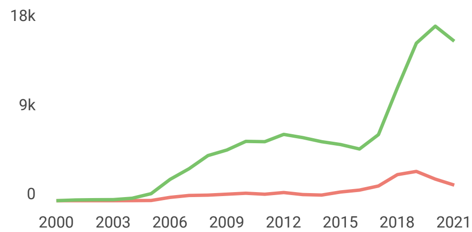

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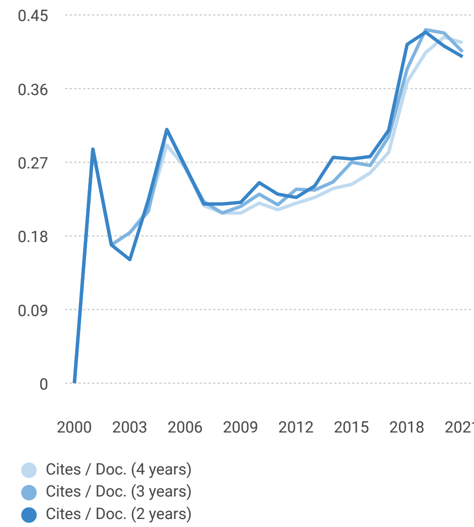

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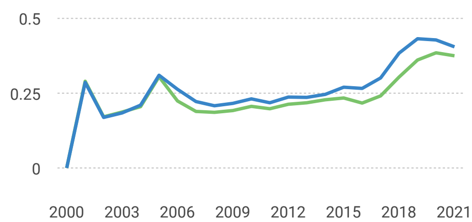

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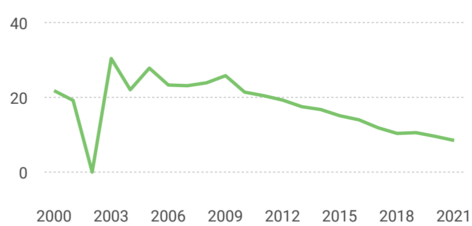

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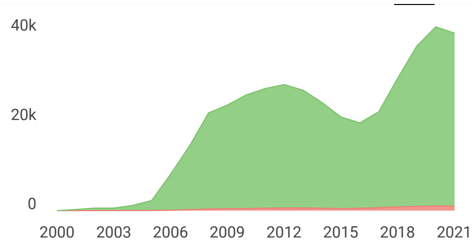

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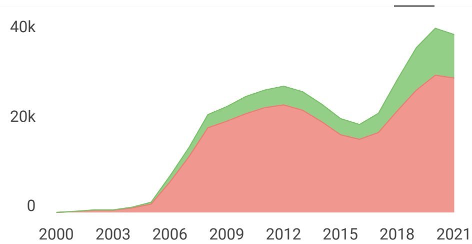

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