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THERMAL EFFICIENCY ANALYSIS ON BOX DRYER EQUIPMENT IN THE CHEMICAL INDUSTRY

Melisa Dwi Savitri[1], Dessy Agustina Sari[1,2,*], Azasfilmi Hakiim[1,2]

[1]Chemical Engineering Program, Engineering Faculty, Universitas Singaperbangsa Karawang, Karawang, Jawa Barat, 41361, Indonesia

[2]Doctoral Program of Chemical Engineering, Chemical Engineering Department, Universitas Diponegoro, Semarang, Jawa Tengah 50275, Indonesia

[*]E-mail: dessy.agustina8@staff.unsika.ac.id

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ABSTRACT

Box dryers are widely utilized in the chemical processing, food, and agricultural industries for drying purposes. The efficiency of these dryers significantly impacts energy utilization. Low thermal efficiency suggests inefficient heat utilization compared to the energy required for drying. Therefore, analyzing thermal efficiency is crucial to optimize energy usage, enhance drying effectiveness, and identify avenues for improvement. This study employs a direct method to assess the thermal efficiency of a box dryer. Data from observations, operational parameters, and literature form the basis for calculating thermal efficiency. Results indicate thermal efficiency ranging from 89.00% to 92.00%, with a drying feed mass rate of 77–91 kg/hour over six hours of operation. These findings classify the box dryer equipment as highly efficient. The industry maintains this efficiency through periodic maintenance schedules and optimization of drying conditions. This research provides a foundational analysis of box dryer performance, aiming to streamline the drying process and minimize energy consumption. The outcomes contribute to ongoing efforts in industrial sectors to enhance operational sustainability and economic viability.

Keywords: box dryer; drying industry; drying rate; heat energy; thermal efficiency.

ABSTRAK

Pengering kotak banyak digunakan dalam industri pengolahan kimia, makanan, dan pertanian untuk tujuan pengeringan. Efisiensi pengering ini secara signifikan berdampak pada penggunaan energi. Efisiensi termal yang rendah menunjukkan pemanfaatan panas yang tidak efisien dibandingkan dengan energi yang dibutuhkan untuk pengeringan. Oleh karena itu, menganalisis efisiensi termal sangat penting untuk mengoptimalkan penggunaan energi, meningkatkan efektivitas pengeringan, dan mengidentifikasi jalan untuk perbaikan. Penelitian ini menggunakan metode langsung untuk menilai efisiensi termal dari pengering kotak. Data dari pengamatan, parameter operasional, dan literatur menjadi dasar untuk menghitung efisiensi termal. Hasilnya menunjukkan efisiensi termal berkisar antara 89,00% hingga 92,00%, dengan laju massa umpan pengeringan 77-91 kg/jam selama enam jam operasi. Temuan ini mengklasifikasikan peralatan pengering kotak sebagai sangat efisien. Industri mempertahankan efisiensi ini melalui jadwal perawatan berkala dan optimalisasi kondisi pengeringan. Penelitian ini memberikan analisis dasar tentang kinerja pengering kotak, yang bertujuan untuk merampingkan proses pengeringan dan meminimalkan konsumsi energi. Hasil penelitian ini berkontribusi pada upaya yang sedang berlangsung di sektor industri untuk meningkatkan keberlanjutan operasional dan kelayakan ekonomi.

Kata Kunci: *pengering kotak; industri pengeringan; laju pengeringan; energi panas; efisiensi termal.*

1. Introduction

Drying reduces the moisture content of the product by evaporating water to a certain level. This process aims to reduce the risk of damage from biological and chemical activities [1]. The drying process requires thermal energy to remove water from the material until it reaches the desired level [2], [3] [4]. Researcher [5] defines drying as a complex operation involving heat and mass transfer and physical or chemical transformation. Furthermore, drying also has the potential to alter product quality through shrinkage, condensation, and crystallization.

Chemical industries, such as PT Maret in West Java, rely on drying to remove moisture. The aim is to improve product quality and efficiency. The industry practices batch-mode drying. This condition keeps the dried material in the dryer for a certain duration [6].

Various types of dryers cater to specific needs, including the rack-type or box dryer that PT Maret uses. With 6 (six) levels, each with shelves for solid materials, this box dryer ensures a thorough drying process. Contact between hot air and the surface of the material occurs when the energy source and air mix in the heater. Then, the heat production is used to carry out the drying process. The blower distributes the hot air evenly throughout the rooms in the box dryer.

Thermal efficiency in box dryers is very important because it affects drying quality and operational costs. Low thermal efficiency leads to increased operational costs due to suboptimal energy use, necessitating more fuel to produce the same quality product. Furthermore, low thermal efficiency can lead to subpar products and diminish their value as the drying process uses ineffective heat. We can assess the box dryer's energy efficiency in drying the material by calculating the thermal efficiency value. This can help optimize energy use and reduce operational costs.

The thermal efficiency of a dryer is critical in evaluating its performance and is influenced by factors such as temperature, relative humidity, air mass flow rate, and moisture content [7]. Drying efficiency [8] relates the relationship between heat loss, dryer design, and hot air distribution in the drying chamber to enable the evaluation of how efficiently the box dryer uses thermal energy.

A low thermal efficiency value indicates that the dryer wastes more heat than the material it is drying [9]. In addition, common problems that can occur in improving thermal efficiency in box dryers include raw material quality, heating system, fuel use, energy use, and environmental conditions [10]. Poor raw material quality, ineffective heating systems, and inefficient use of fuel and energy can all affect the box dryer's thermal efficiency.

Thermal efficiency analysis identifies factors that affect performance and provides a basis for improvements to increase the efficiency of equipment operation. Another activity was to emphasize the importance of this research for optimizing energy use during the drying process to achieve a moisture content of 7.81–9.87% in the March industry.

In addition to impacting energy use, low thermal efficiency can also impact the quality of the final product. By analyzing the thermal efficiency of the box dryer, we can pinpoint the factors influencing its performance, facilitate the necessary enhancements to boost its operational efficiency, and optimize the drying process to preserve product quality. Based on this review, this study aims to analyze the thermal efficiency of box dryers in the March industry to help optimize energy use and maximize the drying process.

2. Methods

Thermal efficiency in box dryer equipment utilizes field data as the main information and literature studies (articles and reference books) to support the estimation. Both data are presented in Table 1 for observation data and companion calculations. The calculation of thermal efficiency in the box dryer is estimated through the use of equations (1) to (4) by utilizing [5].

The thermal efficiency analysis of the box dryer was conducted using experimental procedures.

a. Setting environmental conditions. Controlled environmental conditions include temperature and humidity.
b. Assessment of material weight and initial moisture content. We first weigh the wet material on the tray to determine its weight for drying and to measure its water content using a water content measuring instrument.
c. Drying. We place the dried material in a box dryer and heat it for 6 hours at 230 °C.
d. Assessment of material weight and final moisture content. We removed the dried material from the dryer and weighed it to determine its final weight. We also measured the final moisture content of the dried material using a moisture meter.
e. Thermal efficiency calculation. Once we obtain the overall data, we use the formula from the literature to calculate the thermal efficiency.

Based on the data that has been obtained, problem solving is done with data processing in the following steps: The drying rate is the amount of water evaporated per unit time [11].

$$mass\,rate\,of\,drying = \frac{m_{wet} - m_{dry}}{t} \quad (1)$$

$$m = m_{wet} - m_{dry}$$

where t is the drying time (hours), respectively. The industry provides a 6-hour drying process to achieve the final moisture content of the material.

The overall heat transfer rate (Q) is estimated by utilizing the [5] listed in equation (2) below.

$$Q = (1+\alpha)(Q_1 + Q_2 + Q_3 + Q_4 + Q_5) \quad (2)$$

$$Q_1 = m \times \Delta H_w \quad (2.1)$$

$$Q_2 = m \times C_{pv} \times (T_2 - T_w) \quad (2.2)$$

$$Q_3 = m \times C_{pw} \times (T_w - T_{m1}) \quad (2.3)$$

$$Q_4 = F \times C_{ps} \times (T_{m2} - T_{m1}) \quad (2.4)$$

$$Q_5 = F \times X_{final} \times C_{pw} \times (T_{m2} - T_{m1}) \quad (2.5)$$

The contants of α ranges from 7.5 to 1.0%. This factor is involved as a manifestation of heat loss due to the conduction heat transfer process between the outer surface of the box dryer and the atmospheric air from radiation.

Table 1. Box dryer equipment: operation and literature data

Specification	Description		
Heat capacity	400,000 kcal/h		
Operating temperature	~ 600ºC		
Dimension, m	7.620 × 1.981 × 2.337		
Power of blower	18.5 kW		
Sample of drying	Solid chemicals		
Shape	Tablets		
Dimension, mm	5 x 3		
Loss on ignition (LOI), %	5		
Temperature, ºC			
Inlet of drying air	230	230	230
Exit of drying air	47	46	52
Wet-bulb of inlet air	34.90	34.90	34.90
Inlet of material	54	54	59
Exit of material	223	237	225
Mass of material, kg			
Wet	546	476	461
Dry	493	429	425
Moisture content of material, X, %			
Initial	15.37	16.00	15.02
Final	9.71	9.87	7.81
Supporting Data [12], [13]			
Evaporation heat of water, ΔH_W, kJ/kg	2,378.10 – 2,392.50		
Specific heat of, kJ/kg.ºC,			
Vapor, C_{PV}	1.9850		
Water, C_{PW}	4.174		
Air, $C_{P,\,air}$	1.007 – 1.008		
Specific heat of product, C_{PS}, kJ/kg.ºC	0.8374		

Water evaporation data up to the specific heat for air based on the temperature of exit air, inlet air, wet-bulb of inlet air, and exit air temperature, respectively. Then, the inlet and exit air temperatures, the wet-bulb temperature of the inlet air, the temperature of the material handled at both the inlet and exit, and the mass of the material when the feed is wet (initial) and the output is dry (final) are T_1, T_2, T_{m1}, T_W, T_{m2}, m_{wet}, m_{dry}, $X_{initial}$, and X_{final}, respectively.

The result of equation (2) will lead to the quantity of heat lost (Q_{loss} and thermal efficiency ($\eta_{thermal}$) of the box dryer equipment during the drying process through the following equations (3) and (4).

$$Q_{loss}, \% = \left(\frac{Q_{in} - Q}{Q_{in}} \times \right) 100\,\% \quad (3)$$

$$Q_{in} = G \times C_{p,air} \times (T_1 - T_0) \quad (3.1)$$

$$G = \frac{Q}{C_{p,air} \times (T_1 - T_2)} \quad (3.2)$$

$$\eta_{thermal}, \% = \left(\frac{\sum_{n=1}^{5} Q}{Q_{\square}} \times \right) 100\,\% \quad (4)$$

The values of G and T_0 are the air mass rate required to transfer a certain amount of heat during the drying process, kg/hour, and the atmospheric air temperature of 30 ºC, respectively. Then, $\eta_{thermal}$ is the thermal efficiency of the box dryer equipment.

3. Results and Discussion

The drying rate of the material is the change in the amount of water content in the material that is evaporated during the drying process. This parameter is one of the factors that can affect the thermal efficiency of the box dryer. The percentage decrease in moisture content in the material for six hours gives the value of the drying rate in the box dryer.

The application of equations (1) to (4) helps to calculate the thermal efficiency of the box dryer equipment. The results of this study are displayed in Table 2, and the processed data show a decrease in the drying rate.

Table 2. Heat energy demand and thermal efficiency of the box dryer

Q to-, kJ/h	**Data of Day** First	**Second**	**Third**
1	12,317.06	11,627.55	13,175.55
2	123.78	107.08	188.06
3	-410.84	-387.46	-557.32
4	12,878.37	12,157.37	11,581.24
5	125,009.86	120,041.29	90,439.20
Q =	164,910.06	157,900.42	126,309.40
G, kg/h	894.00	851.34	704.67
Q_{in}	180,229.57	171,630.90	141,920.67
$\eta_{thermal}$, %	91.50	92.00	89.00

Researchers [14] stated that temperature, humidity, airflow velocity, surface area, open or closed drying chamber, and pressure can influence the rate of evaporation of water from the surface of the material. A decrease in the drying rate indicates that suboptimal use of heat energy can reduce the productivity of the box dryer. Researchers [15] stated that lower air temperatures and humidity can contribute to a reduction in the drying rate. Meanwhile, researchers [16] stated that higher temperatures increase the amount of water evaporated.

Thermal efficiency measures the energy used compared to the energy lost during the drying process. The analysis in this study shows that the thermal efficiency ranges from 89.00 to 92.00%. This figure shows the excellent performance of PT Maret box dryer equipment in West Java province. This ternal efficiency is achieved with a heat loss factor value of either 7.5 or up to 1.0% with the difference in heat value (Q_1 - Q_{in}) and G as the mass rate of drying air.

The decrease in thermal efficiency of the box dryer is closely related to the increase in heat loss. Researcher [17] said that uneven heat distribution can cause over- or under-drying of materials. Researchers [18], [19] also added that the difference in the amount of material dried with the same fuel can reduce the efficiency of drying equipment. The use of other types of dryers is an option for circulating hot air according to the characteristics of the material to be dried [20].

The heat loss from the three days of data observation in the March industry was 8.00 to 11.00%. This indicates that the higher the heat loss value, the more heat energy supplied is wasted during the drying process. The high heat loss can be influenced by equipment operational disruptions and possibly leaks in the heating system. Both of these can result in heat in the dryer not being utilized optimally [21]. The impact causes a decrease in thermal efficiency because the heat energy supplied is not used efficiently.

Researchers [22] identified factors such as dryer insulation, size, and pressure as causes of heat loss. The findings of [10], [23] emphasize that higher drying chamber temperatures are capable of providing increased heat loss and further decreasing efficiency. The researcher [24] also added that operational settings such as proper heating and drying air velocity can play an important role in thermal efficiency issues by controlling the drying temperature. The addition of dehumidification agents before heating the air to the burner can reduce the moisture content in the air and reduce the burden on energy sources in producing hot air. This breakthrough has been widely applied in low-food drying [25], [26], [27] to maintain the drying quality in terms of physico-chemical and physical shrinkage. Even further, the involvement of coatings on the outside of the dried material is capable of sustaining low-temperature drying [28], like the use of dehumidification agents.

The analytical results discussed have significant implications for thermal efficiency in drying equipment operations. We can optimize the drying process to achieve better results by understanding the thermal efficiency. For instance, we can adjust operating conditions like drying temperature, time, and air humidity to attain the desired level of dryness. In addition, thermal efficiency analysis helps to know the extent of heat energy used by the dryer and absorbed by the material being dried, so that the use of fuel will more effectively reduce energy costs.

4. Conclusion

Research activities at PT Maret in West Java related to the material drying process with a feed flow rate of 461–546 kg for 6 hours have been carried out. Hot air supply to reduce the moisture content of the material from 15.02-16.00 to 7.81-9.87% amounted to 141,920.67–180,229.57 kJ/hour. Furthermore, the thermal efficiency value of box dryer equipment can reach a range of 89.00–92.00%. The need for regular maintenance becomes the role of maintenance to maintain the thermal efficiency of the box dryer. This agenda is carried out through optimization of the drying rate and paying attention to temperature fluctuations, air circulation, and the presence of equipment insulation in raising the thermal efficiency of the box dryer that has been achieved.

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