Data on exergy and exergy analyses of drying process of onion in a batch dryer

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ABSTRACT

Today’s engineering systems and machine are so sophisticated that mere energy analysis cannot accurately and reliably describe the thermodynamic behaviour, viz-a-viz the energy changes occurring in these complex systems. Hence, a more efficient and realistic parameter that provides us with useful information about thermodynamic losses and energy efficiency improvement potential is the exergy analyses. Fresh samples of onion fruits were washed with distilled water to remove particles and contaminants that can adversely affect the experimental results. Hence, 36.50 g of the sample at different thicknesses of 0.50 cm, 1.00 cm and 1.50 cm were taken into the cabinet dryer for drying at different temperatures of 65 °C, 75 °C, 85 °C and 95 °C and the weight loss at each temperature and thickness was determined with the aid of a digital weighing balance. Hence, it was on this premise that the exergy analyses in terms of exergy loss, exergetic improvement potential and exergetic sustainability index of drying process of onion at different drying air temperatures, drying periods and thicknesses in a cabinet dryer was performed.

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Subject area: Chemical Engineering
More specific subject area: Thermodynamics
Type of data: Tables, figures, images,
Experimental factors: Energy usage optimization in drying process depends on various factors such as air temperature, feeding rates, relative humidity or wet-bulb depression, air velocity, air mass flow rate and particles size, shape and arrangement.
Experimental features: Exergy analysis in terms of exergy inflow, exergy of dried product, exergy outflow, exergy loss, exergy efficiency, exergetic sustainability index and exergetic improvement potential of drying process of onion in a cabinet dryer at different drying periods were evaluated under drying temperatures of 65 °C, 75 °C, 85 °C and 95 °C and particle thickness of 0.50 cm, 1.00 cm and 1.50 cm.
Data source location: Nigeria.
Data accessibility: Data are available within this article

Value of the data

- The data showed the optimum temperature condition for efficient energy usage during the drying of onion in a cabinet dryer.
- The data furnished us with reliable information as regards the energy and exergy efficiency of batch dryers used in various drying processes.
- The data examined the effect of particle size on exergy and exergy efficiency during drying processes.
- The data give us a hint on the likely sources and location of thermodynamic inefficiencies during drying process and where improvement potential is possible.
- The data will serve as guide on dryer selection for various individuals and industries involved in food stuff preservation.

Table 1
Exergy inflow (kJ/s) at various drying temperatures.

| Temperature (°C) | EX_{in} (kJ/s) | EX_{fo} (kJ/s) | EX_{outflow} (kJ/s) |
|-----------------|----------------|----------------|---------------------|
| 65              | 3.7326         | 2.5859         | 6.3185              |
| 75              | 5.7173         | 3.9608         | 9.6781              |
| 85              | 8.0825         | 5.5938         | 13.6763             |
| 95              | 10.8052        | 7.4709         | 18.2761             |
described the exergy of dried products at different temperatures and thicknesses. The exergy outflow at various drying air temperatures and thicknesses is presented in Tables 3a–3d and the exergy loss is showed by Tables 4a–4d. Similarly, the exergy efficiency of the drying process at different drying air temperatures is presented in Fig. 1a–d while the exergetic sustainability index at various temperatures is described by Fig. 2a–d. Finally, the exergetic improvement potential at different drying air temperatures is vividly presented in Fig. 3a–d.

### Table 2a
Exergy of dried product (kJ/s) at 65 °C.

| Time(s) | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
|---------|-------------------|-------------------|-------------------|
| 900     | 2.425892          | 2.471284          | 2.521512          |
| 1200    | 2.378722          | 2.430267          | 2.490297          |
| 1500    | 2.318074          | 2.378996          | 2.452145          |
| 1800    | 2.243950          | 2.317470          | 2.407056          |
| 2100    | 2.156348          | 2.245690          | 2.355030          |
| 2400    | 2.055269          | 2.163655          | 2.296068          |
| 2700    | 1.940713          | 2.071367          | 2.230168          |
| 3000    | 1.812680          | 1.965406          | 2.157332          |
| 3300    | 1.671170          | 1.859445          | 2.081028          |
| 3600    | 1.516182          | 1.743229          | 2.001255          |

### Table 2b
Exergy of dried product (kJ/s) at 75 °C.

| Time(s) | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
|---------|-------------------|-------------------|-------------------|
| 900     | 3.437906          | 3.592653          | 3.739042          |
| 1200    | 3.331977          | 3.497583          | 3.661576          |
| 1500    | 3.197157          | 3.377494          | 3.563452          |
| 1800    | 3.033447          | 3.232387          | 3.475657          |
| 2100    | 2.840847          | 3.062261          | 3.336217          |
| 2400    | 2.619357          | 2.867117          | 3.176120          |
| 2700    | 2.368978          | 2.646955          | 3.000530          |
| 3000    | 2.089708          | 2.401774          | 2.793953          |
| 3300    | 1.781548          | 2.131574          | 2.571883          |
| 3600    | 1.444499          | 1.836356          | 2.329155          |

### Table 2c
Exergy of dried product (kJ/s) at 85 °C.

| Time(s) | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
|---------|-------------------|-------------------|-------------------|
| 900     | 4.330610          | 4.799319          | 5.097298          |
| 1200    | 4.121461          | 4.596531          | 4.919816          |
| 1500    | 3.863101          | 4.346425          | 4.699737          |
| 1800    | 3.555529          | 4.089560          | 4.479659          |
| 2100    | 3.198746          | 3.744821          | 4.174389          |
| 2400    | 2.792751          | 3.352764          | 3.826523          |
| 2700    | 2.337545          | 2.920149          | 3.443161          |
| 3000    | 1.833128          | 2.426989          | 3.003004          |
| 3300    | 1.556313          | 2.196871          | 2.846820          |
| 3600    | 1.279498          | 1.973804          | 2.704834          |
2. Experimental design, materials and methods

The paramount objective of any drying process is the utilization of minimum amount of energy to obtain a maximum amount of moisture removal with a view to achieving the desired product conditions and specifications. Drying is a complex process of heat and mass transfer for removal of moisture from a wet solid. Two separate phenomena are involved in drying. One, moisture must travel from the interior of a material to the surface of that material either by capillary action or diffusion and two, evaporation of the surface water into the surrounding air [1].

Exergy is a parameter of the second law of thermodynamics and it is defined as the maximum work quantity which can be produced by a system from flow of matter, heat or energy when equilibrium is reached with the environment as reference [2]. Exergy is a combined property of a system

| Time(s) | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
|---------|-------------------|-------------------|-------------------|
| 900     | 5.161715          | 5.769821          | 6.258066          |
| 1200    | 4.788759          | 5.398904          | 5.914313          |
| 1500    | 4.326293          | 4.937318          | 5.482418          |
| 1800    | 3.74318           | 4.385064          | 4.962382          |
| 2100    | 3.132833          | 3.742141          | 4.354203          |
| 2400    | 2.401839          | 3.008549          | 3.657883          |
| 2700    | 2.028882          | 2.515642          | 2.873422          |
| 3000    | 1.700681          | 2.266715          | 2.653067          |
| 3300    | 1.461989          | 1.912283          | 2.450341          |
| 3600    | 1.223297          | 1.730946          | 2.326943          |

| Time(s) | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
|---------|-------------------|-------------------|-------------------|
| 900     | 6.158492          | 6.203884          | 6.254112          |
| 1200    | 6.111322          | 6.162867          | 6.222897          |
| 1500    | 6.050674          | 6.111596          | 6.184745          |
| 1800    | 5.976550          | 6.050070          | 6.139656          |
| 2100    | 5.888948          | 5.978290          | 6.087630          |
| 2400    | 5.787869          | 5.896255          | 6.028668          |
| 2700    | 5.673313          | 5.803967          | 5.962768          |
| 3000    | 5.545280          | 5.698006          | 5.889932          |
| 3300    | 5.403770          | 5.592045          | 5.813628          |
| 3600    | 5.248782          | 5.475829          | 5.733855          |

| Time(s) | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
|---------|-------------------|-------------------|-------------------|
| 900     | 9.155206          | 9.309953          | 9.456342          |
| 1200    | 9.049277          | 9.214883          | 9.378876          |
| 1500    | 8.914457          | 9.094794          | 9.280752          |
| 1800    | 8.750747          | 8.949687          | 9.192957          |
| 2100    | 8.558147          | 8.779561          | 9.053317          |
| 2400    | 8.336657          | 8.584417          | 8.893420          |
| 2700    | 8.086278          | 8.364255          | 8.717830          |
| 3000    | 7.807008          | 8.119074          | 8.511253          |
| 3300    | 7.498848          | 7.848874          | 8.289183          |
| 3600    | 7.161799          | 7.553656          | 8.046455          |
and its environment because it depends on the state of both the system and environment. It is neither a thermodynamic property of matter nor a thermodynamic potential of a system and the exergy of a system in equilibrium with the environment is zero [3].

Exergy is conserved only during ideal processes and lost or destroyed in actual processes due to irreversibilities [4].

Exergy analyses is a reliable method to establish strategies to design, implement and operate many industrial processes in which optimal energy usage is sacrosanct with a view to obtaining relevant information pertaining to plant and operation costs, energy conservation, fuel versatility and pollutants level [5,6].

Exergy analysis plays an important role in optimization of drying conditions and drying system performance improvement [7].

**Table 3c**

| Time(s) | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
|---------|-------------------|-------------------|-------------------|
| 900     | 12.41311          | 12.88182          | 13.17980          |
| 1200    | 12.20396          | 12.67903          | 13.00232          |
| 1500    | 11.94560          | 12.42893          | 12.78224          |
| 1800    | 11.63803          | 12.17206          | 12.56216          |
| 2100    | 11.28125          | 11.82732          | 12.23689          |
| 2400    | 10.87525          | 11.43526          | 11.90902          |
| 2700    | 10.42005          | 11.00265          | 11.52566          |
| 3000    | 9.915628          | 10.50920          | 11.08550          |
| 3300    | 9.638813          | 10.27937          | 10.92932          |
| 3600    | 9.361998          | 10.05630          | 10.78733          |

**Table 3d**

| Time(s) | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
|---------|-------------------|-------------------|-------------------|
| 900     | 15.96692          | 16.57502          | 17.06327          |
| 1200    | 15.59396          | 16.20410          | 16.71951          |
| 1500    | 15.13149          | 15.74252          | 16.28762          |
| 1800    | 14.57952          | 15.19026          | 15.76758          |
| 2100    | 13.93803          | 14.54734          | 15.15940          |
| 2400    | 13.20704          | 13.81375          | 14.46308          |
| 2700    | 12.83408          | 13.32084          | 13.67862          |
| 3000    | 12.50588          | 13.07192          | 13.45827          |
| 3300    | 12.26719          | 12.71748          | 13.25554          |
| 3600    | 12.02850          | 12.53615          | 13.13214          |

**Table 4a**

| Time(s) | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
|---------|-------------------|-------------------|-------------------|
| 900     | 0.160008          | 0.114616          | 0.064388          |
| 1200    | 0.207178          | 0.155633          | 0.095603          |
| 1500    | 0.267826          | 0.206904          | 0.133755          |
| 1800    | 0.341950          | 0.268430          | 0.178844          |
| 2100    | 0.425552          | 0.340210          | 0.230870          |
| 2400    | 0.530631          | 0.422245          | 0.289832          |
| 2700    | 0.645187          | 0.514533          | 0.355732          |
| 3000    | 0.773220          | 0.620494          | 0.428568          |
| 3300    | 0.914730          | 0.726455          | 0.504872          |
| 3600    | 1.069718          | 0.842671          | 0.584645          |
2.1. Experimental Procedure

Fresh samples of onion fruits were bought from local market in Ota, Ogun state, Nigeria. The onions were washed with distilled water to remove particles and contaminants that can adversely affect the experimental results. Hence, 36.50 g of the sample at different thicknesses of 0.50 cm, 1.00 cm and 1.50 cm were taken into the cabinet dryer for drying at different temperatures of 65°C, 75°C, 85°C and 95°C and the weight loss at each temperature and thickness was determined with the aid of a digital weighing balance.

| Table 4b | Exergy loss (kJ/s) at 75°C. |
|----------|-----------------------------|
| Time(s)  | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
| 900      | 0.522894          | 0.368147          | 0.227158          |
| 1200     | 0.628823          | 0.463217          | 0.299224          |
| 1500     | 0.763643          | 0.583306          | 0.397348          |
| 1800     | 0.927353          | 0.728413          | 0.485143          |
| 2100     | 1.199953          | 0.898539          | 0.624583          |
| 2400     | 1.341443          | 1.093683          | 0.784680          |
| 2700     | 1.591822          | 1.313845          | 0.960270          |
| 3000     | 1.871092          | 1.559026          | 1.166847          |
| 3300     | 2.179252          | 1.829266          | 1.388917          |
| 3600     | 2.516301          | 2.124444          | 1.631645          |

| Table 4c | Exergy loss (kJ/s) at 85°C. |
|----------|-----------------------------|
| Time(s)  | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
| 900      | 1.26319            | 0.79448           | 0.49650           |
| 1200     | 1.47234            | 0.99727           | 0.67398           |
| 1500     | 1.73070            | 1.24737           | 0.89406           |
| 1800     | 2.03827            | 1.50424           | 1.11414           |
| 2100     | 2.39505            | 1.84898           | 1.41941           |
| 2400     | 2.80105            | 2.24104           | 1.76728           |
| 2700     | 3.25625            | 2.67365           | 2.15064           |
| 3000     | 3.76067            | 3.16710           | 2.5908            |
| 3300     | 4.03748            | 3.39693           | 2.74698           |
| 3600     | 4.31430            | 3.62000           | 2.88897           |

| Table 4d | Exergy loss (kJ/s) at 95°C. |
|----------|-----------------------------|
| Time(s)  | 0.50 cm Thickness | 1.00 cm Thickness | 1.50 cm Thickness |
| 900      | 2.30918            | 1.70108           | 1.21283           |
| 1200     | 2.68214            | 2.07200           | 1.55659           |
| 1500     | 3.14461            | 2.53538           | 1.98848           |
| 1800     | 3.69658            | 3.08584           | 2.50852           |
| 2100     | 4.33807            | 3.72876           | 3.11670           |
| 2400     | 5.06906            | 4.46235           | 3.81302           |
| 2700     | 5.44202            | 4.95526           | 4.59748           |
| 3000     | 5.77022            | 5.20418           | 4.81783           |
| 3300     | 6.00891            | 5.55862           | 5.02056           |
| 3600     | 6.24760            | 5.73995           | 5.14396           |
2.2. Exergy Analyses

Exergy analyses are typically performed to determine the location, type and magnitude of thermodynamic inefficiencies during drying process by applying the second law of thermodynamics [8]. The reduced form of exergy equation is given by Eq.(1) below:

\[
Ex = mc \left[ (T - T_\infty) - T_\infty \ln(T/T_\infty) \right]
\]  

(1)

Where:

- \( Ex \) = Exergy (kJ/s)
- \( C \) = specific heat \([kJ/kg K]\)
- \( T_\infty \) = reference temperature (25 °C or 298 K)
- \( T \) = drying air temperature (K)
- \( m \) = mass flow rate of fresh or dried product.

The specific heat of the fresh and dried product \( C_p [kJ/kg K] \) was also calculated by using the Eq (2).

(9) proposed by [9] as:

\[
c_p = 4.187X_m + 1.424X_c + 1.549X_p + 1.675X_f + 0.837X_a
\]  

(2)

where \( X_m \) = moisture component (%), \( X_c \) = carbohydrate component (%), \( X_p \) = protein component (%), \( X_f \) = fat component (%) \( X_a \) = ash component (%)

The exergy inflow represents the maximum amount of useful available energy that is being supplied into any system (e.g batch dryer) to cause a change in either the properties of the system or any material within the surroundings of the system.

Exergy inflow can be expressed by Eq. (3) below

\[
Ex_{in} = Ex_{ain} + Ex_{FO}
\]  

(3)
Fig. 2. a: Exergetic sustainability index at 65 °C. b: Exergetic sustainability index at 75 °C. c: Exergetic sustainability index at 85 °C. d: Exergetic sustainability index at 95 °C.

Fig. 3. a: Exergetic improvement potential at 65 °C. b: Exergetic improvement potential at 75 °C. c: Exergetic improvement potential at 85 °C. d: Exergetic improvement potential at 95 °C.
ExI = exergy inflow (kJ/s),
Exain = exergy inflow of air (kJ/s) and
ExFO = exergy of fresh onion (kJ/s)

Similarly, Eq. (4) gives the general form of exergy outflow.

\[ Ex_{out} = Ex_{ajt} + Ex_{D0} + Ex_{ldc} \] (4)

\( Ex_{out} \) = exergy outflow (kJ/s)
\( Ex_{ajt} \) = exergy outflow of air (kJ/s)
\( Ex_{D0} \) = exergy destruction (kJ/s)

Since mass flow rate of drying air was evenly distributed throughout the whole cross section of drying chamber,
Hence, initial mass flow rate of air is equal to the final mass flow rate of air

\[ m_{a1} = m_{a0} \] (5)

Thus,

\[ Ex_{ain} = Ex_{ajt} \] (6)

The exergy destruction, that is, exergy loss resulting from heat loss through the drying chamber can be described by Eq. (7) [10,11].

\[ Ex_{ldc} = Q_{ldc} \frac{1 - \frac{T_{\infty}}{T_{\text{avg}}}}{C_{0} C_{21}} \] (7)

Where \( T_{\text{avg}} \) is the average temperature of the drying chamber and \( Q_{ldc} \) is the heat loss by drying chamber which is assumed to be negligible. Hence, \( Ex_{ldc} = 0 \).

Exergy loss is an energy parameter that is often confused with exergy destruction. It represents the transfer of exergy from a system to its external environment in an irreversible manner (the discharge of a non-useful energy stream into the surroundings) while exergy destruction is an internal phenomenon that characterizes exergy destruction due to irreversibilities within a component of a system (e.g., exergy destruction during combustion process).

Exergy loss was calculated by using Eq. (8),

\[ \text{Exergy loss} = \text{Exergy inflow} - \text{Exergy outflow} \] (8)

Exergy efficiency is a critical indicator of the quality level of the converted energy. The exergy efficiency of a system is maximized when exergy loss is minimized and it is mathematically represented by Eq. (9).

\[ \text{Exergy efficiency} = \frac{\text{Exergy outflow}}{\text{Exergy inflow}} \] (9)

It can also be expressed by Eq. (10)

\[ \text{Exergy efficiency} = 1 - \frac{\text{Exergy loss}}{\text{Exergy inflow}} \] (10)

The exergetic sustainability index (ESI) is a dimensionless parameter that is based on the exergy analysis and it is defined as the relationship between the input exergy and exergy losses of a system. The parameter provides us with useful information about the process influence on the environment [12]. Improvement on exergy efficiency will naturally translate to higher sustainability index.

Mathematically, it is represented by Eq. (11).

\[ ESI = \frac{1}{1 - \text{Exergy efficiency}} \] (11)
Exergy improvement potential measures are necessary to increase exergy efficiency with a view to reducing environmental impact by reducing energy losses [13]. Lower exergy efficiency would lead to higher improvement potential [14,15].

\[
EIP = \frac{\text{Exergy loss}}{(1 - \text{Exergy efficiency})}
\]  

(12)

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