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Development of equations for estimating energy requirements in palm-kernel oil processing operations

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Abstract

A study was conducted to determine the energy consumption in palm-kernel oil (PKO) processing operations as carried out in nine PKO mills in Nigeria. The mills were equally stratified into three categories to represent different mechanization levels and production capacities. Mathematical expressions were developed to evaluate the energy requirement for each of the seven readily defined unit operations, namely: palm-nut drying, palm-nut cracking, palm-kernel crushing, palm-kernel roasting, PKO expression, PKO sifting and PKO bottling/pumping. The equations were exploited to compute energy expenditure by the mills using measured input data. Empirical equation was developed for each unit operation to relate energy requirement to palm-nut/kernel input. The application test of the equations indicated that about 352 MJ, 232 MJ and 177 MJ was averagely needed to process 1000 kg of palm-nut in the small, medium and large-scale mill, respectively, while energy requirement for each unit operation in each mill category was also estimated.

Keywords: Palm-kernel oil; Energy requirement; Unit operations; Empirical equations; Nigeria

1. Introduction

Energy is an indispensable commodity for the economic growth and development of any nation. Nigeria has abundant energy resources, which play a dual role in the country. The energy resources generate foreign exchange reserves, which the government uses for the various development programmes. Energy is also an essential input to the growth and development of the various sectors of the economy. The role of energy consumption in the country may appear enormous but the overall energy consumption is still very low when the energy consumption per capita (13.4 GJ) is compared to that of developed countries such as UK and Germany whose energy consumption per capita in 1988 were 144.7, 164.1 and a developing country like South Africa with a value of 182.6 GJ (Adenikinju, 1995; Akinbami, Ilori, Adeniyi, & Sanni, 2001) (see Fig. 1).

Industrialised agriculture relies on energy to carry out the desired operations and obtain high processing efficiencies in mechanization of crop handling and conveyance and thermal processing, to assure safe storage of agricultural products, and conversion processes that create new forms of food. Energy is primarily used for agricultural operations such as land preparation, planting and weeding, irrigation, harvesting, threshing and transportation (Jekayinfa, 2001; Ozkan, Akcaz, & Fert, 2004).

Historically, oil palm has played an important part in the Nigerian economy. In 1900, when the total agricultural commodities amounted to 95.6% of total exports, the contribution made by palm oil and palm-kernel alone was 81.6% or $2,242,000. This continued to be the pattern of export trade until the mid—1920s when increasing contributions were made by cocoa and groundnuts (Anyaegbu, 1978; Meshack – Hart, 1990). During the period 1959–1965, commercial exports of palm oil and palm-kernels averaged 163,000 and 414,000 ton per annum, respectively. Export of palm produce from Nigeria, therefore, constituted nearly 30% (palm

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Nomenclature

E_d	energy requirement for palm-nut drying (J)
E_c	energy requirement for palm-nut cracking (J)
E_r	energy requirement for palm-kernel roasting (J)
E_c	energy requirement for palm-nut crushing (J)
E_e	energy requirement for palm-kernel oil expression (J)
E_s	energy requirement for palm-kernel oil sifting (J)
E_{bp}	energy requirement for palm-kernel oil bottling/pumping (J)
E_T	total energy requirement
t	time taken for a particular operation (i.e., t_d, t_c, t_r, t_{cr}, t_e, t_s, t_{bp}) (h)
C	heating value of fuel used for a particular operation (i.e., C_d, C_c, C_r, C_{cr}, C_e, C_s, C_{bp}) (J/kg or J/l)
W	quantity of fuel used for a particular operation (i.e., W_d, W_c, W_r, W_{cr}, W_e, W_s, W_{bp}) (l)
P	electrical power consumed for a particular operation (i.e., P_d, P_c, P_r, P_{cr}, P_e, P_s, P_{bp}) (kW)
N	number of persons involved in a particular operation (i.e., N_d, N_c, N_r, N_{cr}, N_e, N_s, N_{bp})
K	efficiency of the electric motor used for a particular operation (i.e., K_d, K_c, K_r, K_{cr}, K_e, K_s, K_{bp})

Subscripts

d	drying
c	cracking
r	roasting
cr	crushing
e	oil expression
s	sifting
bp	bottling/pumping

oil) and 50% (palm-kernel) of the world trade in these commodities. The production of palm oil in Nigeria reached its lowest ebb during the Nigerian civil war (1966–1970). It was estimated in 1978 that Nigeria became a net importer of palm oil with 3000 ton worth $16 million. (Anyaegbu, 1978; Ejemba, 1989; Udom, 2002). Table 1 shows the past performance of Nigeria in world production of palm-kernel and palm oil, respectively, for 1995–1998 (USDA, 1998).

1.1. Oil palm composition and processing

Both the pulp and the kernel yield oil and each has a different fatty acid composition. The pulp makes up 60–90% of the fruit's weight. On a dry weight basis, more than 70% of the pulp and 40% of the kernel consists oil. A fruit bunch will yield about 20% palm oil and 2% palm-kernel oil (Ejemba, 1989; Encyclopedia of Food Science & Technology, 1991).

For edible fat manufacture, palm oil is bleached. Palm oil contains saturated palmitic acid, oleic acid and linoleic acid, giving it a higher unsaturated acid content than palm-kernel or coconut oils. Palm oil is used for manufacture of soaps and candles and more recently, in manufacture of margarine and cooking fats. Palm oil is used extensively in tin plate industry, protecting cleaned iron surfaces before the tin is applied. Oil is also used as lubricant, in textile and rubber industries (Ejemba, 1989; Encyclopedia of Food Science & Technology, 1991).

The resulting bye-product, the palm-nut, is further broken by the use of palm-nut cracker for the recovery of palm-kernel encased in it without damaging the kernel. The mechanical form of cracking involves the use of cracking machine being driven by hand or motor at a very high speed and causing an impact to be made on the palm-nut either through the use of hammer mills or by the collision that occurs on the hard surface wall of the inner casing of the machine. Depending on the types of expeller, the palm-kernels may need to be roasted, for example, in an oil drum roaster, which is hand-rotated over a fire. Expellers use a horizontally rotating metal 'screw' which feeds oil-bearing raw material into a barrel-shaped outer casing with perforated walls. Raw materials are continuously fed to the expeller, which grinds, crushes and presses the oil out as it passes through the machine. The pressure ruptures the oil cells in the raw material, and oil flows through the perforations in the casing and is collected in a trough underneath. Most small expellers are power-driven, typically requiring about 3 hp and are able to process between 8 and 45 kg per hour of raw material depending upon the type of expeller used. Bigger units processing greater quantities are available for use in larger mills.

A limited number of studies have been reported in the literature on the development of energy use models. These include models for vegetable canneries (Vergara, Rao, & Jordan, 1978), tobacco curing system (Cundiff & Dodd, 1981), rice processing (Chang, Chang, & Kim, 1996; Ezeike, 1981; Verma, 2002), cashew nut processing (Jekayinfa & Bamgboye, in press), spinach processing (Chhinnan et al., 1980) and sunflower oil expression (Farsaie & Singh, 1985). The present study used similar procedure for the breakdown of the unit operations in PKO production and determination of energy consumed in each.

In 1987, the Federal Government of Nigeria introduced the Structural Adjustment Programme (SAP) which led to the prohibition of importation of some essential products (including soap, cooking oil and body/hair cream) as policy measures to revive the economy, minimize the dependence on importation and to build a non-oil export based