*Misr J. Ag Eng. 19 (2) : 467 – 477*

# CORN RESIDUE AS ENERGY SOURCE

**EL-SAID RAMADAN EL-ASHRY[1]**

## ABSTRACT

The objective of this work was to determine the energy values of corn residue. Bomb calorimeter tests were performed both on representative cob sections and representative plant sections (excluding kernels) All tests were made on non-dried samples and thus reflected variations in energy as a function of moisture content. The combustion results of cob versus the entire plant were compared at different harvested kernel moisture contents to determine the practical use of each fuel, from a combustion standpoint.The result indicated: that cobs and stalks contained near identical energy values at the same moisture content and for the same weight of dry matter; cobs averaged 5.7 percent higher in energy due to a lower moisture content when cobs and stalks were harvested simultaneously; and cob energy can be predicted as a function of kernel moisture content. Favorable weather conditions could possibly place stalk moisture below cob moisture, making stalk energy at harvest higher than cob energy (per unit weight). Composite energy was considerably reduced due to the stalk component.

## INTRODUCTION

Modern agriculture is heavily dependent up on fossil fuels. The tremendous productivity of agriculture has resulted from advanced processing and mechanization which are dependent on low – cost energy supplied by combustion of fossil fuels. Crop residues left in the field following harvest have been proposed as a low-cost, renewable energy source.

The total annual Egyptain crop residues is about $40 \times 10^5$ tons (FAO 2000). The rapid increases in crop residue results not only loosing a value of potential material but also deteriorate local environment. Utilization of this enormous amount of residues in a useful way will help keeping friendly environment. Energy production from agricultural residues enjoyed numerous research work during the last two decades. Solid. liquid and gas fuels were produced from agricultural residues through biological and thermochemical conversion processes sites.

Corn harvesting leaves the entire plant except the kernels as residue. The residue is then processed by stalk choppers, disked, and eventually incorporated into the soil However. Buchele and Marley (1976) show that only about one half of this residue is needed on the field to maintain its fertility. Corn residue consists of cobs and the remainder of the plants (stalks), excluding the kernels. Little research has been conducted to determine which part of the residue, cobs or corn stalks, can be of more practical use as fuel.

[1] Assoc. Prof. Ag. Eng. Dept. Fac. of Agric. Univ of Alex.

Basic knowledge concerning the combustion of cobs and stalks is limited. A few combustion tests have been conducted on small, oven dried samples (Kajewski et al 1977). These studies indicate that cobs possess lower moisture contents and thus higher energy values per unit weight as compared to stalks (Dahlberg 1977). However, these studies fail to account for variability that may exist in cob and stalk moisture content. The American Society of Mechanical Engineers (ASME, 1974) power test code defines the higher heating value as the high heat of combustion or the heat of reaction for complete combustion or the gross heat of combustion.The higher heating value of a fuel may be determind using a bomb calorimeter as described by the American Society for testing and Materials (ASTM, 1981). During this test. fuel is dried until it is moisture – free. Fuel is burned in the calorimeter and the amount of heat released is measured. In a bomb calorimeter, all of the water vapor formed from the hydrogen in the fuel during combustion is condensed to a liquid since the products of combustion are cooled back to their original temperature. This procedure gives the higher heating value. The lower heating value (net heating value) is the heat energy released if water produced by hydrogen in the fuel remains a gas rather than being condensed to a liquid. Kajewski et al. (1977) used a value from a bomb calorimeter and deducted the heat energy of vaporization for moisture in the fuel.

The objective of this research was to determine and compare energy values of corncobs and cornstalk at various cob, stalk, and kernel moisture contents on corn samples.

## MATERIAL AND METHODS

Corn samples were collected between August 28 and September 13 in 1998 at the Agricultural Experiment Station Faculty of Agricuture, Alexandria University. Samples were obtained from a field 110m long and 12 rows deep. Row spacing averaged about 1m. Approximately 15 corn rows bordered the east, west, and south sided of the field.

The length of the field was divided into four, 30m sections. In order to account for moisture varibility in the corn, four samples were collected each day. A total of 48 samples (one stalk per sample) were obtained for each sample. Stalks were cut 10 cm above the ground approximating the level at which harvesting equipment would cut the stalk. Careful handling was maintained to avoid any loss of material from the sample.

Each sample was weighed and divided into component parts so that tests could be conducted on each part. The component parts for one sample included the kernels, cob, leaves, husks and stalk. The component parts for the remaining three samples included the kernels, cobs and composite sections. The composite section consisted of leaves, husks, and stalks. Since corn stalks as currently harvested consisted of a mixture of leaves, husks, and stalks, primary interest focused on testing composite sections. However, *in order to determine the effect of each elemental part on the* composite section. individual tests were made on the leave, husks, and stalk for one sample.

After weighing a 800 gm scale (0.01 gm accuracy), each component was tightly wrapped and sealed in two heavy duty freezer bags to prevent moisture losses or gains (stalks were cut in approximately 10 equal lengths to make packaging possible). Samples were then packed into a paper bag and refrigerated to reduce plant respiration rates.

Approximately 20 grams of each sample were used to conduct moisture content tests by oven drying at 105° C for 72 hours (ASAE S352). One moisture test was made per component part. All moisture contents were calculated on wet basis (w.b)

A Parr Adiabatic Series 1200 Oxygen Bomb Calorimeter (Parr Instrument Company) was used to determine the gross energy content of one gram samples of each component. All samples were weighed on Balance to .0001 gram accurracy. Triblicate combustion tests on each component were made by modifying the procedure established by the National Bureau of standards (Jessup 1960). This procedure modified in these samples were not pelleted due to moisture changes which would occur in the pelleting process. Since many samples were high in moisture, pelleting compressed moisture from the samples.

Standardization tests on the calorimeter were made three times during the course of experimentation. These tests were performd to find the effects of the thermal capacity of the bomb and calorimeter vessel. The standardization tests followed the same procedure as other combustion tests except benzois acid. a fuel of known heating value 26.470 MJ/kg was used.

Combustion tests on 288 sample components were performed on a wet basis. In addition, 16 tests were made on cobs, stalks, leaves, and husks on an oven dry basis. Since bomb calorimeter results express energy values were calculated on a wet basis. Net energy was considered important since it was the actual value obtained from combustion in a furnace. Unlike gross energy, net energy does not include the latend heat of vaporization recovered during the condensation of the water vapor.

All plots were tested for single linear (straight line) and other order responses. A Statistical Analysis System (SAS) stepwise general linear modelling procedure was used in testing several relationships that predicted cob and stalk energy. The statistical significance of the relationships were determined by considering $R^2$ values, F-tests on the sample variances, and t-tests on the estimated regression coefficients. Statistical analyses also included the computation of the mean values, standard deviations of the means, and standard errors of the mean values, standard deviations of the means, and standard errors of the estimated regression coefficients.

## RESULTS AND DISCUSSION

Cob and composite combustion results and cob, composite, and kernel moisture contents were recorded for each sample in Table (1).

**Table (1): Moisture content and Energy result for indvidual samples.**

| Sample | Kernel M.C KMC % (w.b) | Cob M.C CMC % (w.b) | Cob Energy (CE) MJ/kg | Composite COM M.C % (w.b) | Composite Energy (COME) MJ/kg |
|---|---|---|---|---|---|
| 1 | 22.25 | 31.06 | 13.125 | 43.62 | 10.910 |
| 2 | 19.06 | 19.00 | 15.292 | 14.83 | 16.274 |
| 3 | 21.24 | 28.91 | 14.018 | 40.24 | 11.750 |
| 4 | 16.86 | 13.25 | 16.593 | 14.07 | 16.448 |
| 5 | 18.52 | 20.87 | 15.016 | 18.84 | 14.819 |
| 6 | 25.62 | 46.01 | 9.728 | 16.40 | 9.707 |
| 7 | 26.15 | 47.00 | 10.827 | 47.40 | 11.332 |
| 8 | 23.04 | 31.77 | 12.735 | 23.71 | 14.673 |
| 9 | 24.49 | 42.15 | 11.375 | 46.28 | 10.041 |
| 10 | 23.63 | 37.23 | 11.970 | 41.28 | 11.102 |
| 11 | 19.50 | 24.85 | 14.400 | 28.18 | 14.060 |
| 12 | 19.14 | 25.70 | 11.975 | 41.98 | 11.067 |
| 13 | 18.68 | 21.24 | 14.991 | 24.91 | 14.297 |
| 14 | 19.64 | 19.00 | 15.416 | 12.05 | 16.857 |
| 15 | 18.13 | 17.19 | 15.842 | 32.44 | 13.032 |
| 16 | 22.95 | 30.15 | 13.433 | 14.66 | 16.350 |
| 17 | 18.31 | 15.33 | 16.092 | 36.89 | 12.019 |
| 18 | 22.83 | 36.60 | 12.267 | 43.57 | 11.377 |
| 19 | 17.10 | 15.90 | 16.060 | 12.00 | 16.756 |
| 20 | 16.20 | 16.26 | 15.899 | 39.57 | 11.732 |
| 21 | 15.28 | 16.21 | 15.757 | 24.98 | 13.822 |
| 22 | 20.04 | 25.65 | 14.243 | 17.64 | 15.600 |
| 23 | 19.76 | 21.70 | 14.919 | 41.65 | 10.814 |
| 24 | 20.14 | 21.17 | 14.953 | 28.53 | 13.339 |
| 25 | 18.21 | 19.25 | 15.380 | 35.06 | 12.417 |
| 26 | 19.64 | 31.02 | 13.142 | 14.31 | 16.249 |
| 27 | 20.09 | 23.41 | 14.635 | 17.62 | 15.524 |
| 28 | 23.37 | 33.42 | 12.763 | 62.98 | 7.0.72 |
| 29 | 19.14 | 18.11 | 15.475 | 15.54 | 16.335 |
| 30 | 21.21 | 32.00 | 12.090 | 35.90 | 11.782 |
| 31 | 21.79 | 31.99 | 13.023 | 49.12 | 9.9.13 |
| 32 | 20.80 | 27.55 | 13.760 | 19.55 | 15.142 |
| 33 | 15.87 | 15.81 | 15.966 | 41.41 | 10.856 |
| 34 | 22.42 | 35.53 | 12.263 | 56.95 | 8.223 |
| 35 | 18.44 | 22.48 | 14.609 | 11.29 | 17.010 |
| 36 | 17.15 | 15.52 | 16.154 | 12.80 | 16.613 |
| 37 | 16.53 | 17.06 | 15.661 | 11.11 | 16.896 |
| 38 | 23.11 | 37.37 | 11.830 | 19.39 | 14.963 |
| 39 | 25.44 | 40.10 | 11.255 | 41.43 | 11.059 |
| 40 | 19.91 | 20.58 | 14.994 | 29.31 | 13.183 |
| 41 | 20.19 | 26.33 | 13.993 | 48.68 | 10.173 |
| 42 | 15.82 | 14.87 | 16.014 | 18.47 | 16.290 |
| **Average** | **20.99** | **25.87** | **14.04** | **29.68** | **13.280** |

Cob moisture varied between 13.25% to 47.00% with averge of 25.86% and cob energy varied between 9.73 MJ/kg to 16.59 MJ/kg with average of 14.05 MJ/kg. Composite moisture varied between 11.11% to 62.98% with average 29.68%. and composite energy varied between 7.07 MJ/kg to 17.01 MJ/kg with a mean of 13.28 MJ/kg. Thus, cob energy averaged 5.7% higher than composite energy.

Composite energy differed considerably with previous studies. Kajewski et al. (1977) reported that cornstalks (composites) contained 16.6 MJ/kg on an oven dry basis. This value was substantially less than 17.01 MJ/kg determined in this research. Energy differences may be attributed to differences in moisture content. representative sampling procedures, and chemical natures of the samples.

The chemical nature of the cornstalk may also have varied. Cellulose and lignin typically make up 80 to 95% of the dry weight of biomass materials. Since these materials are the combustible components, a variation in total or relative amounts of cellulose and lignin may have resulted in different combustion results. Composition could be caused by different sampling procedures and / or different plant varieties.

Cob energy reasonably agreed with Dahlberg (1977) and Porter and Wiebe (1984) who reported oven dry values of 18.562 MJ/kg and 18.617 MJ/kg respectively. Anderson's (1972) listed a lower of 17.375 MJ/kg. This closely corresponded to determine by this study as shown in Table (1).

A general linear modelling procedure was used in testing several relationships for predicting cob and composite energy. As shown in Figure (1) the relationship between cob moisture content % (w.b) and cob energy (MJ/kg). The best-fit equation is given in the following:

$$\mathbf{CE = 18.889 - 0.185\ CMC} \qquad \mathbf{(1)}$$

Where:

CE = Cob energy (MJ/kg)
CMC = Cob moisture content, (wb, %)

Analysis of variance on the relationship yielded $R^2$ was equal to 0.99 . The F- and t- tests on the regression variances and estimated coefficients were significant at the 0.0001 level.

The relationship between composite moisture content percent (w.b) and composite energy (MJ/kg) was also plot as shown in Figure (2). It defined by the following Equation:

$$\mathbf{COM.E = 19 - 0.187\ COM.MC} \qquad \mathbf{(2)}$$

Where:

COM.E = Composite Energy (MJ/kg)
COM. MC = Composite moisture content, (w.b, %)

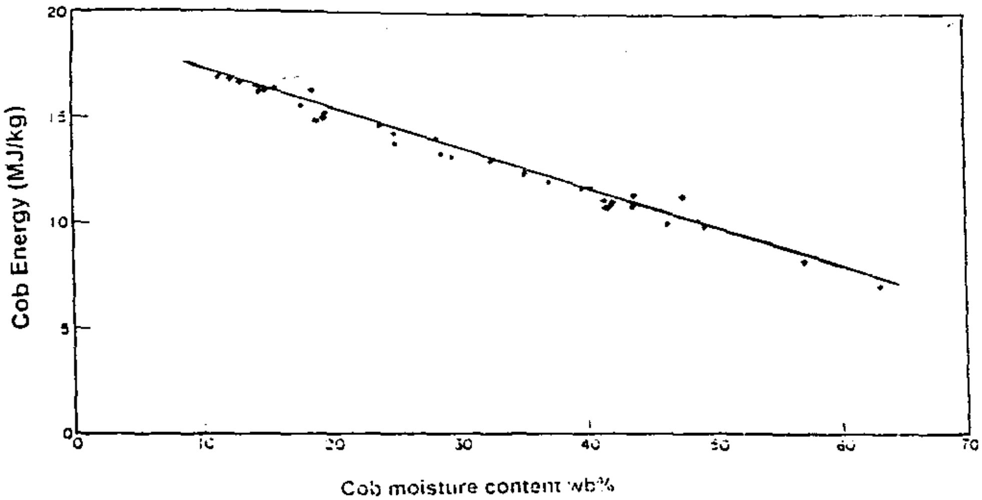


Figure (1): The relationship between cob moisture content and cob energy

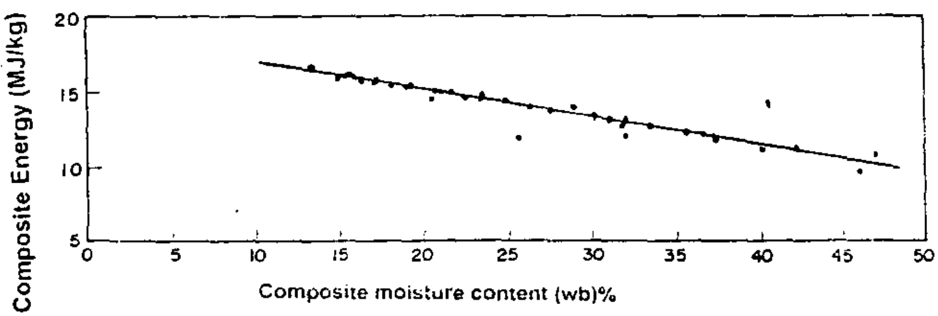


Figure (2): The relationship between composite moisture content

As shown in Figures (1) and (2) and in Equations (1) and (2) were superimposed showing nearly indentical energy values at the same moisture level. Although cob and composite energy were equal at the same moisture content. their moisture contents may have differed considerably when harvested resulting in large energy differences.

As shown in Figure (3) there are good relationship between cob moisture content and kernel moisture content. The close relationship between cob and kernel moisture allowed cob energy to be predicted from the kernel moisture content.Cob energy expressed as a function of kernel moisture content (KMC,wb) was tested. Figure (4) shows this relationship. And it's defined by the following Equation:

$$CE = 11.95 + 0.776\ KMC - 0.032\ KMC^2 \qquad (3)$$

The F and T. tests were significant at the 0.0001 level

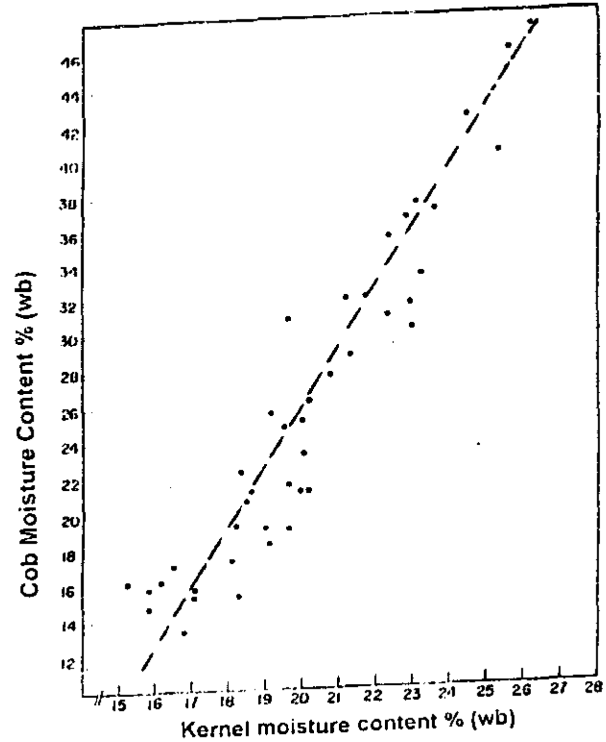


Figure (3): Cob moisture content as a function of kernel moisture content

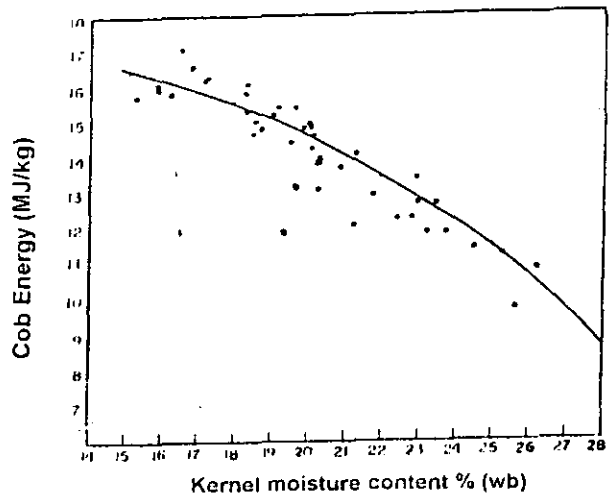


Figure (4): Cob Energy as a function of kernel moisture content

From a combustion standpoint, experimental evidence indicated cobs offered two advantages over composite sample: cob energy averaged 5.7% higher than composite energy and cob energy could be predicted from the kernel moisture content. Cob energy averaged 5.7% higher (per unit weight) than composite energy because the average moisture content was lower over the sampling period. Composite moisture content of the samples depended on environmental conditions and exhibited the lowest and highest moisture content compared to cobs. Cob moisture did not vary as much as composite moisture since the kernels and husks provided an effective barrier againts environmental conditions.

On the other hand, favorable (dry) environmental conditions may place composite moisture below cob moisture, making composites more advantages on a heat content basis. Out of a total of 42 observations, eight composite samples contained moisture contents between 11.11% and less than 15%. Cobs had two samples between 13.25% and less then 15% moisture content. Although the concept of harvesting the driest portion of the composites in a field may be impractical, the possibility exists to gauge composite harvesting with favorable environmental conditions. Composites harvested after several consecutive warm, sunny, and windy days may contain less moisture and more energy than cobs.

Since one sample was divided into stalk, leaves, and husks, the composite energy and moisture content of this sample were calcutated from the weight fractions, moisture contents, and combustion results of the component parts, as shown in Table (2).

In most cases, composite energy was considerably reduced due to the stalk component as shown in Figure (5). Stalks were exceptionally high in moisture content compared to other components and represented large fraction of the total composite weight as shown in Table (2). The weight fraction of component part of composite was 0 591, 0.232 and 0.176, for stalk, leaves and husks rep.

## CONCLUSIONS

The following conclusions were reached from this research:

1- Cob and composite energy were nearly identical at the same moisture content. The dry unit weight energy of cobs, composites, stalks, leaves, and husks was similar. Cob energy (per unit weight) averaged only 5.7% higher than composite energy due to the lower overall moisture content of the cobs.

2- The close relationship between cob and kernel moisture allowed cob energy to be predicted from the kernel moisture content. Cob energy could be reasonably predicted from the kernel moisture content. Composite energy could not be predicted from the kernel moisture content.

3- Composite energy was considerably reduced due to the stalk component; however the percent of energy for stalk to total composite energy was about 45%.

Table (2): Composite moisture contents and energy

| Sample | Component Part | M.C % (w.b) | Weight fraction | Composite M.C % (w.b) | Composite Energy MJ/kg |
|---|---|---|---|---|---|
| 1 | Stalk | 50.33 | 0.5143 | 25.885 | 5.014 |
| | Leaves | 12.16 | 0.2258 | 2.746 | 3.771 |
| | Husks | 13.36 | 0.2599 | 3.472 | 4.244 |
| | | | | 32.103 | 13.029 |
| 2 | Stalk | 55.59 | 0.6018 | 33.454 | 5.399 |
| | Leaves | 12.57 | 0.2402 | 3.019 | 3.932 |
| | Husks | 18.80 | 0.1580 | 2.970 | 2.235 |
| | | | | 39.443 | 11.566 |
| 3 | Stalk | 53.55 | 0.6907 | 36.987 | 5.922 |
| | Leaves | 11.92 | 0.1896 | 2.260 | 3.112 |
| | Husks | 17.58 | 0.1197 | 2.104 | 1.846 |
| | | | | 41.351 | 10.880 |
| 4 | Stalk | 76.15 | 0.6111 | 46.535 | 2.756 |
| | Leaves | 14.38 | 0.1297 | 1.865 | 2.089 |
| | Husks | 32.37 | 0.2592 | 8.390 | 3.355 |
| | | | | 56.79 | 8.2 |
| 5 | Stalk | 14.47 | 0.4422 | 6.399 | 7.368 |
| | Leaves | 14.20 | 0.3429 | 4.869 | 5.570 |
| | Husks | 12.92 | 0.2149 | 2.777 | 3.502 |
| | | | | 14.045 | 16.440 |
| 6 | Stalk | 59.25 | 0.6264 | 37.114 | 4.732 |
| | Leaves | 30.39 | 0.2234 | 6.789 | 3.460 |
| | Husks | 30.44 | 0.1502 | 4.572 | 1.939 |
| | | | | 48.475 | 10.131 |
| 7 | Stalk | 51.21 | 0.6308 | 32.303 | 6.066 |
| | Leaves | 10.90 | 0.2081 | 2.268 | 3.445 |
| | Husks | 11.92 | 0.1611 | 1.920 | 2.664 |
| | | | | 36.491 | 12.175 |
| 8 | Stalk | 13.38 | 0.4342 | 5.810 | 7.128 |
| | Leaves | 12.17 | 0.3453 | 4.202 | 5.829 |
| | Husks | 11.82 | 0.2205 | 2.606 | 3.682 |
| | | | | 12.618 | 16.639 |
| 9 | Stalk | 62.31 | 0.6558 | 40.862 | 5.963 |
| | Leaves | 14.38 | 0.1842 | 2.649 | 2.948 |
| | Husks | 23.25 | 0.1600 | 3.72 | 2.404 |
| | | | | 47.231 | 11.315 |
| 10 | Stalk | 61.26 | 0.5473 | 33.528 | 4.063 |
| | Leaves | 15.39 | 0.2978 | 4.583 | 4.667 |
| | Husks | 18.62 | 0.1549 | 2.884 | 2.306 |
| | | | | 40.995 | 11.036 |
| 11 | Stalk | 56.70 | 0.6086 | 34.508 | 4.666 |
| | Leaves | 15.18 | 0.2472 | 3.752 | 4.001 |
| | Husks | 23.13 | 0.1442 | 3.335 | 2.135 |
| | | | | 41.595 | 10.802 |
| 12 | Stalk | 77.12 | 0.7363 | 56.783 | 3.346 |
| | Leaves | 12.51 | 0.1470 | 1.839 | 2.447 |
| | Husks | 39.89 | 0.1167 | 4.655 | 1.353 |
| | | | | 63.277 | 7.146 |
| **average** | **Stalk** | **52.61** | **0.591** | **32.51** | **5.202** |
| | **Leaves** | **14.68** | **0.233** | **3.403** | **3.773** |
| | **Husks** | **21.18** | **0.176** | **3.617** | **2.639** |
| | | | **1.000** | **39.53** | **11.614** |

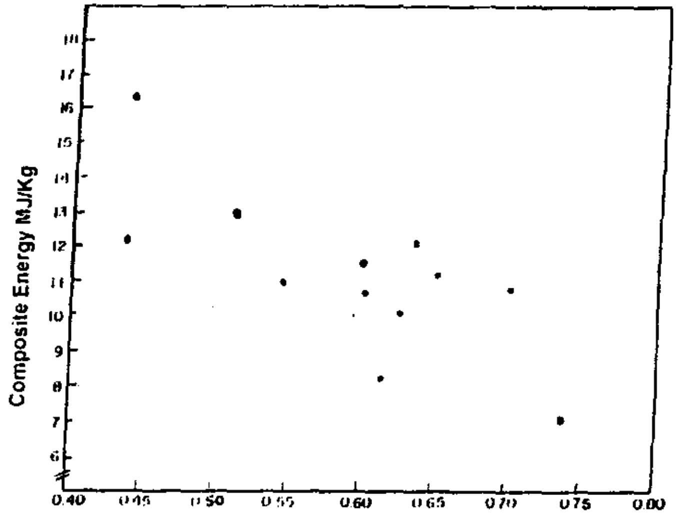


Figure (5): Effect of stalk weight fraction on total composite Energy

## REFERENCES


Anderson's cob Division Processing Group. 1972. Physical properties and uses of the Anderson's corncob products. Maumee. Ohio.

ASAE, D241.2 Density, specific gravity, and weight moisture relationships of grain for storage. ASAE Standard.

ASAE, S352 Moisture measurement. ASAE standard.

ASME, 1974, combustion fundamentals for waste incineration. The American Society of Mechanical Engineers, New York.

ASTM, 1981. ASTM standard D2015 calorimetric method for determining gross calorific value of solid fuel by adiabatic oxygen bomb calorimeter test. In Robert lukens et. Al. (eds) Annual book of ASTM standards. American society for testing and materials, philadelphia. Pennsylvania.

Buchele, W.E. and S.J. Marley. 1976. Energy production from crop residue. Jour paper No. J-9248 of the Iowa Agriculture and Home Economics Experiment Station, Ames.

Clark and Lathrop. 1953. Chemical composition of corn cobs, Northern Regional Research Laboratory.

Dahlberg, R.W. 1977 Corn cobs- an energy source for drying seed. 32nd corn & Sorghum Research conference, American Seed Trade Association.

FAO (Food and Agriculture Organization of the united Nation 2000. Quarterly bulletin of statistics, New York.

Horsfield, B., H. Doster, and R. Peart. 1977. Drying energy from corn cobs: a total system. In: Agriculture and Energy (W. Lockeretz, Editor), Academic Press, Inc., pp. 47 – 64).

Jessup, R.S. 1960. Precise measurnnent of heat of combustion with a bomb calorimeter. National Bureau of Standards Monograph 7.

Kajewski, A.H., S. J. Marley, and W.F. Buchele. 1977. Drying corn with a crop residue fired furnace. Presented at the Winter Meeting of the ASAE.

Kiesselback, T.A. 1950 Progressive development and seasonal variations of the corn crop. Res. Bull. 166, Agricultural Experiment Station, Lincoin, Nebraska.

Porter. J.C. and R. Wiebe. 1984. Gasification of agricultural residues. ATC- 174, USDA, peoria. Illinois.

## الملخص العربى

# مخلفات محصول الذرة كمصدر للطاقة

د/ السعيد رمضان العشرى*

الهدف من هذا البحث هو تحديد محتوى الطاقة فى الكتل الحيوية لمخلفات محصول الذرة، استخدم لهذا الغرض جهاز كالورى ميتر لتقدير الطاقة لكل من كيزان وأقلاح وسيقان وأوراق وأغلفة الكيزان. وأوضحت النتائج أن محتوى الطاقة للكيزان وخليط مخلفات الذرة (سيقان وأوراق وأغلفة الكيزان) متساوى عند ثبات نسبة الرطوبة، وأن محتوى الطاقة للكيزان يزيد بنسبة ٥,٧% من محتوى الطاقة لخليط مخلفات الذرة . وقد امكن إيجاد علاقة للتنبؤ بمحتوى طاقة الكيزان كدالة بنسبة رطوبة الأقلاح وأوضحت النتائج أيضاً أن محتوى الطاقة لخليط مخلفات الذرة ينخفض نتيجة زيادة نسبة وزن السيقان وهذا يرجع إلى زيادة الرطوبة فى السيقان عن باقى أجزاء النبات وعلى أى حال فإن محتوى الطاقة للسيقان يمثل بنحو ٤٥% من إجمالى محتوى طاقة الكمبوست.

* استاذ مساعد بقسم الهندسة الزراعية- كلية الزراعة - جامعة الإسكندرية