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'ALUATION OF SOME MOISTURE METERS -OR USE IN FOOD HANDLING AGENCIES IN PAKISTAN

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1. INTRODUCTION

1.1 GENERAL:

Grain is a living organism which respires by taking in oxygen and releasing corbondioxide. During this process carbohydrates of the endosperm are transformed into energy and water and heat is released. The respiratory rate of grain is dependent upon temperature, relative humidity and moisture content. Respiration of grains under cool and dry condition is slow as compared to warm and moist conditions. In the entire process of respiration the key factor is moisture content, whereas other physical factors only influence the moisture content directly or indirectly. This is because of the hygroscopic nature of grain. If there is comparatively more moisture in the grain than in the air around the grain, the moisture in grain will be pushed out into the air. Under the conditions in which grain is dry and there is more moisture in air (R.H) the grain shall absorb moisture. The speed of the process is regulated by the temprature. At each temprature the produce have a pattern of gaining moisture (adsorption) or loosing moisture (desorption) under different relative humidity conditions untill a equilibrium is achieved. If plotted it appears as a characeristic sigmoid curve and the relationship is termed as moisture content/relative humidity isotherm.

1.2 IMPORTANCE OF MOISTURE CONTENT:

The atmospheric and intergranular humidity accompnied with temperature effect not only regulates the moisture content of grain but also regulates the insect and mould growth in the stored produce. At higher R.H levels the chance of insect and mould attack/growth are greater than at lower R.H The process has a biological feed back as the mould and insect due to thier respiration further liberate water and

generate heat causing not only increase in moisture content of the grain but also enhancing the insect and mould development.

In short moisture causes deterioration through following ways:

i) increased respiration
ii) increased insect growth
iii) increased mould growth
iv) decreased viability of grains

There are certain indirect causes also, as the insect or mould infested grain shall have some nuitritive deplition and will fetch less price in the market. To avoid this safe limits of moisture content of various grains had been set for the purpose of storage under different environmental conditions.

In procurement or selling operation the moisture is bought and sold by weight. It is the amount of water for which the trade is made. The grain with more moisture content shall have less dry matter which is the vital object of buisness. Therefore in developed countries the procurement and sales are based on the amount of moisture in the commodity.

1.3 TYPE OF MOISTURE CONTENT:

Grain moisture content is defined as the amount of water in the grains and is denoted in terms of percentage. Some of the water in the grain is in the form of chemical binding which is termed as bound moisture, whereas other is held loosely, which is referred as free (adsorbed and absorbed) moisture. The percentages of bound and free moisture varies with the type of commodity. In practice moisture content in grain is determined on dry and wet basis. The difference between the two is given below:

i) % Moisture content (Wet basis) $= \frac{\text{Weight of Water}}{\text{Weight of Water} + \text{Weight of Dry matter}} \times 100$

ii) % Moisture content (Dry basis) $= \frac{\text{Weight of Water}}{\text{Weight of dry matter}} \times 100$

The determination on wet basis is commonly used in practical storage operations.

1.4 DETERMINATION OF MOISTURE CONTENT:

Determination of accurate moisture content of grain is essential before buying, storage or in any other postharvet operation. In broad terms there are three methods of moisture determination.

1.4.1 Oven methods:

In this the commodity is dryed on a certain temperature for a known period to remove the water. The difference in initial weight and the weight after drying determines the percentage moisture content. There are several combinations of temperature and time of drying in the oven used and recommended by various agencies e.g. 130°C for 1 hour, 120°C for 4 hours, 105°C for 16 hours etc. The International Standard Organisation (ISO) in R 712 recommends drying a ground sample for 2 hours at 130°C ± 3°C. The oven method is considered to be the most accurate but has some drawbacks as it is time consuming and not rapidly repeatable. Nonetheless it is used as a reference method for calibration/ evaluation of other moisture measuring methods.

1.4.2 Chemical methods:

In these methods free moisture in the ground material is extracted by a reagent. Such methods are to be calibrated against a reference method of drying upto a constant weight under reduced pressure.

1.4.3 Electrical methods:

It is the rapid method of measurement with rapid repeatability. The moisture content is measured by specially designed moisture meters, which are of following two types.

i) Resistance: Which works on the principle of measuring the electrical resistance of the grain. The resistance is high in dry grains but drops with the increase in grain moisture.

ii) Capacitance: Which measures the capacitance properties of the grain. In these the amount of electric charge between the two plates of a capacitor is seperated by a layer of grains and which varies with the grain moisture content.

The electrical methods do not give results which are consistently related to those given by oven method. In resistant types a small drop in moisture content may produce large increase in resistance or large increase in moisture content may produce a small decrease in resistance. This is the reason that most of the resistant type moisture meters are relatively accurate in the middle of thier range with a plus or minus 0.5 percent error which may be 1.0-1.5 percent at their extreme ends. Same is true in capacitance type of meters which may be very accurate in a limited range and inaccurate at the other ranges. Besides these another significantcause of error which is normally neglected is the difference of varieties of the same cereal. The differences in the chemical composition of various varieties effect the accuracy of measures to a smaller or larger extent. Temperature also effects the accuracy of the meters, therefore, temperature corrections are to be made with some meters. The new type of moisture meters have an automatic system which initially correct and adjust the temperature and then display the final moisture reading.

It is noteworthy that resistance at low moisture content is very high, therefore below 8-9 percent moisture content resistance type of moisture meters do not work. In capacitance type of moisture meters the packing of grain between the capacitor walls has a significant role in determining the accuracy and repeatability. These moisture meters are unsuitable for ground material but are capable of measuring a wider range of moisture content in whole grains than resistance type with a useful lower limit of 6 percent and upper of 26-29 percent. There are more than 50 types of electric moisture meters used worldwide and developed to work under specific or wide range of conditions.

1.5 FACTORS EFFECTING CHOICE OF MOISTURE METERS:

Most of the moisture meters are either accurate in the range of 13-16 percent moisture as they are mostly developed by the industrialised western countries considering their own requirements or are accurate in the middle of their range due to the reasons stated earlier. Unfortunately no meter is known to have developed considering the local grain conditions of Pakistan. Under these circumstances one way of overcoming the problem could be the screening of various meters for their reliability under Pakistani grain conditions. The factors which could have an effect on determining the suitability of moisture meter are summarized as under:

i) Resolution -- to differentiate between two moisture contents which are close in value.

ii) Repeatability -- to give a constant reading when same sample is tested several times.

iii) Reliability -- variation between meters of same brandwhen measuring moisture content of the same sample.

iv) Stability -- drifts of measurements.

v) Weight -- easiness in handling in particular of field type meters.

vi) Robustness -- to stand mechanical stress in transportation.

vii) Cost -- the availability of most suitable meter at a reasonable rate.

viii) Battery -- operatability on battery and availability of batteries.

ix) Range of produce -- meter caliberation for the commodities of interest.

x) Range of moisture content -- like resistant type do not work below 9 %.

xi) Sample size and weight -- must have representative sample size, otherwise repeated sampling shall increase the measurement time.

xii) Speed of measurement -- important when large number of samples are to be measured.

There are other factors also like ease of correction/ adjustment, ease of measurement, temperature corrections (manual or automatic), ease of cell cleaning, etc. etc.

1.6 MOISTURE METER CALIBRATION:

Electrical moisture meters cannot measure the moisture content of a commodity accurately due to a variety of reasons. The parameters of measurements of these moisture meters are affected not only by the moisture content but also by the sample size, shape, temperature and physical and chemical constitution of the commodity. The relationship between the electrical properties and moisture content will therefore vary depending on the type of variety and condition of the produce being measured. It is therefore essential to test and calibrate the relationship between electrical reading and the actual moisture content, determined by standard oven method.

Since different varieties of the same commodity may behave differently. It is therefore essential that the moisture meter calibration should be made against each of the variety to obtain a clear picture.

1.7 BACKGROUND AND OBJECTIVES OF THE PRESENT STUDY:

Pakistan being an underdeveloped country has its primitiveness in grain procurement, storage, marketing and other handling operations. One of the drawbacks of present system of wheat procurement and distribution is the fact that no emphasis has been laid on determination of moisture content at any stage. The procurement is based on subjective criteria of cursory visual inspection for determining the moisture content of grain rather than objective test of measurement with the help of moisture meters. The FAQ procurement specifications of Provincial Food Departments do not even include the moisture content. This have resulted in several problems, viz. buying of excess water at the price of wheat, no incetive to the suppliers for providing dry wheat and subsequent deterioration during storage due to procurement of moist grain. The international agencies supporting Pakistan on improvement in grain storage and preservation had been continously floating the idea of moisture content measurement. In fact through IDA's World Bank Project a number of moisture meters of Black Digital, model TD1, OGA (Japan) and few of Dicky John (USA) were provided to the Provincial Food Departments for their day to day use. Keeping the issue of their non use due to present legislature aside, it is important to say that the meters provided by the agency were not checked to determine their suitability for use under Pakistani conditions. Of course the calibration with standard oven method can be made of any moisture meter within a given range and a particular wheat variety. The fact that the wheat procurement agencies do not have any concept of variety at the time of procurement in

public sector have made the situation rather complex, as the accuracy of meters vary from one variety to another. Toover come this problem a need was felt to evaluate the available moisture meters against prevelant wheat varieties grown in Pakistan in order to determine a suitable one which could give comparatively reasonable and accurate results on a range of wheat varieties and can be used in day to day operations of food handling agencies. An attempt of calibrating moisture meter with standard oven method for six Pakistani wheat varieties was earlier made by De Lima and Salihah (1984) but those varieties have now not remained prevalent and also the purpose of that study was different.

The objectives of this study were multifold and are summarised below:

i) To calibrate six commonly available moisture meters in Pakistan against reference air oven method using most prevalent Pakistani wheat varieties.

ii) To develop calibration graphs of each moisture meter against each variety and also mixture of varieties.

iii) To evaluate the most appropriate moisture meter, which could be used against the prevalent wheat varieties with minimal error due to varietal differences at low moisture range of Pakistani wheat.

2. METHODOLOGY

2.1 MOISTURE METERS:

The following moisture meters were evaluated for their accuracy with respect to various wheat varieties against the reference oven method.

i) Burrow digital moisture computer -700
ii) Kett Reciter - L
iii) Black digital TD 1-OGA
iv) Protimeter - Grain master
v) Dole - 500
vi) Dicky John DJGMT

The salient characteristics of these moisture meters are given in Table 1.

2.2 WHEAT VARIETIES:

The following wheat varieties were used for determination of moisture content by various moisture meters and air oven reference method.

i) Pak-81
ii) Blue Silver
iii) Pavan
iv) Punjab - 81
v) LU - 81
vi) WL - 711
vii) Sonalika
viii) Sample of mixed varieties

2.3 CONDITIONONG OF VARIETIES AT VARIOUS MOISTURE CONTENTS:

For each of the variety 4 kg of clean, fresh grain was obtained and its moisture content measured by air oven method. The samples of each variety were dried by placing

le-1. Moisture meters used in the study and their characteristics.

Name of meter	Model	Manufacturer	Type	Moisture Range	Accuracy	Weight	Size	Power supply
Burrows digital moisture computer	700	Burrows equipment Co. Illinois. U.S.A.	Capacitance	0 - 100%	0.1% m.c.	7.8 Kg.	$15\frac{1}{2}'' \times 12\frac{1}{4}'' \times 6\frac{3}{8}''$	AC mains or 12 Volts car battery
Protimeter grain master	TW-70	Protimeter Ltd. Bucks, England.	Resistance	10 - 40%	0.5% m.c.	1.5 Kg.	$7\frac{3}{4}'' \times 4\frac{3}{4}'' \times 1\frac{3}{4}''$	18 Volts transister battery
Kett.Riceter	L	Kett. electric Co.. Tokyo, Japan.	Resistance	10 - 30%	0.1% m.c.	0.64 Kg.	$6\frac{1}{2}'' \times 3\frac{3}{4}'' \times 1\frac{3}{4}''$	12 Volts transister.
Dickey John moisture tester	DJGMT	Dickey John Co. Illinois U.S.A.	Capacitance	10 - 40%	0.5% m.c.	1.3 Kg.	$9\frac{3}{4}'' \times 7\frac{3}{4}'' \times 4\frac{3}{4}''$	9 Volts transister battery.
Dole digital grain moisture tester	500	Seed buro International equipment Co. Chicago, U.S.A.	Capacitance	7 - 40%	0.1% m.c.	0.45 Kg.	$6'' \times 3'' \times 2''$	9 Volts transister battery.
O.G.A Black digital	TD-1	OGA electronic Co. Japan.	Resistance	9 - 30%	-	0.6 Kg.	$7\frac{1}{4}'' \times 3\frac{1}{2}'' \times 1\frac{3}{4}''$	12 Volts transister battery.

them in trays with nearly uniform grain layers of 1.5 cm thick in a mechanically ventilated air oven at 45°C. The trays in which the samples of various varieties were placed were weighed before and after heating. The required loss in moisture (weight) was determined using the following equation.

$$B = \frac{A\ (100 - a)}{100 - b}$$

Where B = Final wt. of sample after drying

A = Initial wt. of sample

a = Initial moisture content of sample

b = Dried moisture content of sample

In this way varieties under test were dried to obtain a uniform moisture content of 7 percent. Each of the sample was then divided by means of a riffle divider to obtain several sub-samples of about 250 gms each. Each of the sub-sample was weighed accurately and then placed in a plastic jar of about 1 litre capacity. The sub-samples of each of the variety were adjusted to a range of moisture content between 7 - 17 percent. This was done by adding measured quantities of water by means of a pipette on the walls of jars (Gough 1975). The amount of distilled water added to obtain desired moisture content in the sub-samples of each variety was calculated by followig equation (Pixton, 1967).

$$\text{Amount of water to be added (ml)} = \frac{W1\ (M1 - M2)}{100 - M2}$$

Where W1 = Initial weight of grain (gms)

M1 = Initial moisture content (%)

M2 = Final moisture content (%)

The water added containers were made air tight by covering them with lids and then using a squash tape. The samples in which lower moisture content was desired were kept at room temperature, whereas samples in which 15 or more percent moisture content was desired were kept in a refrigerator at 5°C (Gough, 1983). The jars were continously turned upside down for the first four hours. Thereafter the process was done 2-3 times a day for 3 weeks. This was to ensure the even distribution of moisture within each of the sub-sample (jar).

2.4 MOISTURE CONTENT DETERMINATION BY MOISTURE METERS.

After 3 weeks the jars of various wheat varieties were opened and their moisture content was measured on all the six types of moisture meters. The results were recorded on a proforma. The moisture meters were used as per instruction given by the manufacturers. For moisture meters having calibration charts on them (Viz., Dicky John, Dole 500) the charts were neglected to prevent double calibration and direct read out was compared with the oven standards. The other necessary precautions regarding correct use of moisture meters were also followed.

2.5 REFERENCE AIR-OVEN MOISTURE CONTENT DETERMINATION.

For the purpose of determination of moisture content of the conditioned samples of various wheat varieties from which reading by moisture meters had been obtained, a mechanically ventillated Blue-M Oven was used. The method followed for determination was that of International Standard Organisation (ISO) R-712. The empty oven was heated and adjusted at 130°C± 3°C. Standard aluminium containers (empty) of 5 cm diameter 2 cm depth alongwith their lids were cleaned, oven dried and then cooled in dessicators. Each of the empty container was then weighed along with its lid and marked accordingly.

From each of the conditioned sub-sample of each variety about 25 gms of wheat was taken and ground in a Quacker City mill No.4 to obtain standard particle size. 5 gm of each of the ground sample was placed in the preweighed and labelled aluminium container using a scoop. It was then covered with its corresponding lid, weighed on a fisher analytical balance (0.1 mg accurate). The containers were then placed in already heated air oven at 130°C for 2 hours after uncovering their lids (placed along their sides in the oven). The containers were than covered with their corresponding lids and removed from the oven and placed in desiccators for cooling for 45 minutes. After which they were reweighed.

The percent moisture content was determined by the following formula.

$$\% \text{ m.c} = \frac{(A - B) \times 100}{A}$$

Where A = Initial mass in gms. of the test portion

B = Mass in gms. of the dry test portion.

The same process was adopted for the samples conditioned to various moisture levels of a mixture of varieties.

2.6 REPLICATES

For each determinations three replicates were taken.

3. RESULTS

3.1 RELATIONSHIP BETWEEN OVEN STANDARD METHOD VALUES WITH THOSE OBTAINED BY VARIOUS MOISTURE METERS.

Tables 2 to 7 outline the relationship between moisture content (%) as determined by oven standard method and by various types of moisture meters in terms of regression equations, correlation coefficient and coefficient of determination. For each wheat variety and each moisture meter type two regression equations are given. The first expresses the regression of moisture meter readings (Y) on the oven standard (X) and the second expresses the regression of oven standard (X) on the moisture meter values (Y). The former can predict the moisture meters reading given the oven standard observation, while the latter predicts the oven standard observation given a moisture meters reading. The correlation coefficient indicates the strength of the relationship between the two types of observations. On the other hand, coefficient of determination tells the percentage of variation accounted for by one variable (reading) in determining the other variable. The regressions of moisture meters readings on oven standard (Y on X) are plotted in Figs. 1 to 8 for various varieties (a to h). The results for each meter type are outlined in the sequel.

3.1.1 Burrows digital 700 moisture computer:

It is apparent from Table 2 that the degree of relationship (r) between moisture meter readings and oven standard values were highly significant ($p < 0.001$) for all varieties including the mixture of varieties. Very high correlations were found for Pak-81, Pavan, Punjab-81, LU-26 and Sonalika. For Punjab-81 99.47% of variation in meter reading could be explained by oven reading and vice versa. Fig. 1a- 1h show the regression of moisture readings on the oven standards for different varieties. Given the oven

standard value the moisture meter reading can be predicted by these graphs. Highest level of accuracy of prediction can be made for Punjab-81 while relatively lowest, though still highly significant for the mixture of varieties. It is noteworthy that the Burrows moisture computer can be set for any variety by using the slope and the intercept of the regression equation.

Table-2. The relationships between readings of Burrows digital moisture computer-700 and Moisture Content as determined by Oven Standard Method.

VARIETY	Regression Equation for Burrows digital-700 Moisture Computer(Y) to Oven Standard Method(X).	Correlation Coefficient(r)	Coefficient of Determination(r2)
PAK-81	Y=0.83X+2.55 X=1.18Y-2.84	0.9318 ***	0.9837
BLUE SILVER	Y=0.82X+2.45 X=1.16Y-2.44	0.9809 ***	0.9623
PAVAN	Y=0.93X+1.26 X=1.05Y-1.16	0.9927 ***	0.9854
PUNJAB-81	Y=0.80X+2.64 X=1.24Y-3.22	0.9973 ***	0.9947
LU-26	Y=0.90X+1.49 X=1.08Y-1.44	0.9916 ***	0.9834
WL-711	Y=0.89X+1.90 X=1.09Y-1.77	0.9869 ***	0.974
SONALIKA	Y=0.82X+2.45 X=1.19Y-2.74	0.9915 ***	0.9832
MIXED	Y=1.02X+0.40 X=0.92Y+0.26	0.9731 ***	0.947

*** p (0.001

3.1.2 Protimeter-grain master:

Table 3 presents the regression equations for the relationships between moisture meter readings and the oven standards while Fig 2a-2h exhibit the regression of moisture meter readings on oven standards graphically. For this meter

the tightest relationship was for WL-711 and relatively lowest degree of relationship (though still highly significant, $p < 0.001$) for Pavan variety. Varieties Pak-81 Punjab-81, LU-26 Sonalika and mixed also gave very high levels of correlations indicating that the equations are capable of prediction with high degree of accuracy.

Table-3. The relationships between readings of Protimeter(Grain Master) and Moisture Content as determined by Oven Standard Method.

VARIETY	Regression equation for Protimeter(Y) to Oven Standard Method(X).	Correlation Coefficient(r)	Coefficient of Determination(r2)
PAK-81	Y= 1.02X+2.42 X= 0.96Y-2.18	0.9935 ***	0.9871
BLUE SILVER	Y= 1.20X+0.22 X= 0.80Y+0.27	0.9826 ***	0.9656
PAVAN	Y= 0.78X+4.73 X= 0.99Y-2.11	0.8816 ***	0.7773
PUNJAB-81	Y= 1.12X+1.71 X= 0.87Y-1.25	0.9903 ***	0.9808
LU-26	Y= 1.12X+1.60 X= 0.87Y-1.21	0.9927 ***	0.9856
WL-711	Y= 1.13X+1.71 X= 0.87Y-1.42	0.997 ***	0.9941
SONALIKA	Y= 1.15X+1.35 X= 0.85Y-0.94	0.9915 ***	0.9832
MIXED	Y= 1.13X+2.25 X= 0.87Y-1.83	0.9945 ***	0.989

*** $p < 0.001$

3.1.3 Kett Riceter-L moisture meter:

The regression equations between moisture meter and oven standard values are presented in Table 4 and the regressions of meter values on oven standards for various varieties in Fig. 3a-3h. This meter showed the highest levels of correlations between moisture meter values and oven standards ($p < 0.001$). Exceptionally high levels of

correlations (r= 0.9989) were given by varieties Pavan and Sonalika. The high order of linear correlations give high levels of the accuracy of prediction to the regression equations which are highly reliable in this case.

Table-4. The relationships between readings of Kett Riceter-L Moisture Meter and Moisture Content as determined by Oven Standard Method.

VARIETY	Regression Equation for Kett Riceter-L moisture meter(Y) to Oven Standard method(X).	Correlation Coefficient(r)	Coefficient of Determination(r2)
PAK-81	Y= 0.97X+0.41 X= 1.02Y-0.35	0.9974 ***	0.9948
BLUE SILVER	Y= 1.05X-0.51 X= 0.94Y+0.52	0.9984 ***	0.9969
PAVAN	Y= 1.09X-0.83 X= 0.91Y+0.78	0.9989 ***	0.9979
PUNJAB-81	Y= 0.98X+0.53 X= 1.00Y-0.40	0.9951 ***	0.9902
LU-26	Y= 1.02X+0.027 X= 0.97Y+0.0057	0.9987 ***	0.9975
WL-711	Y= 1.18X-2.01 X= 0.83Y+1.86	0.9928 ***	0.9858
SONALIKA	Y= 1.07X-0.91 X= 0.93Y+0.87	0.9989 ***	0.9979
MIXED	Y= 1.11X-1.04 X= 0.89Y+0.98	0.9978 ***	0.9957

*** p< 0.001

3.1.4 Dickey John model DJGMT moisture meter:

Table 5 gives the regression equations and the degree of relationships between moisture meter values and the oven standards, while Figs. 4a -4h show the regressions of meter readings on oven standards graphically. Reasonably high degree of relationships existed (all correlations being highly siginficant, p< 0.001). The highest level of the accuracy of prediction was given by Pak-81 while the (relatively) lowest by Sonalika.

Table-5. The relationships between readings of Dickey John DJGMT Moisture Meter and Moisture Content as determined by Oven Standard Method.

VARIETY	Regression Equation for Dickey John moisture meter(Y) to Oven Standard Method(X).	Correlation Coefficient(r)	Coefficient of Determination(r2)
PAK-81	Y= 0.53x+5.99 X= 1.87Y-11.16	0.9974 ***	0.9949
BLUE SILVER	Y= 0.53X+5.56 X= 1.69Y-8.45	0.9551 ***	0.9122
PAVAN	Y= 0.57X+5.36 X= 1.70Y-8.82	0.9861 ***	0.9725
PUNJAB-81	Y= 0.48X+5.80 X= 2.03Y-11.69	0.9949 ***	0.9899
LU-26	Y= 0.54X+5.28 X= 1.80Y-9.31	0.9898 ***	0.9797
WL-711	Y= 0.50X+6.26 X= 1.68Y-8.91	0.9241 ***	0.854
SONALIKA	Y= 0.56X+5.19 X= 1.71Y-8.39	0.9781 ***	0.9568
MIXED	Y= 0.65X+4.49 X= 1.41Y-5.45	0.9615 ***	0.9244

* * * p < 0.001

3.1.4 Dole -500 moisture meter:

The regression equations are presented in Table 6 while the regression of moisture meter readings on oven standards are plotted in Figs. 5a - 5h. Though all correlations were highly significant, the values ranged from 0.8884 for Sonalika to 0.9563 for Pak-81. High levels of predications can be made for varieties Pak-81, Pavan, Punjab-81 and the mixture of varieties.

Table-6. The relationships between readings of Dole-500 Moisture Meter and Moisture Content as determined by Oven Standard Method.

VARIETY	Regression Equation for Dole-500 moisture meter(Y) to Oven Standard Method(X).	Correlation Coefficient(r)	Coefficient of Determination(r^2)
PAK-81	Y= 0.69X+4.66 X= 1.31Y-5.07	0.9563 ***	0.9146
BLUE SILVER	Y= 0.78X+3.64 X= 1.03Y-1.41	0.8978 ***	0.806
PAVAN	Y= 0.55X+5.90 X= 1.60Y-8.10	0.937 ***	0.8781
PUNJAB-81	Y= 0.78X+3.32 X= 1.11Y-2.17	0.9358 ***	0.8758
LU-26	Y= 0.74X+4.11 X= 1.19Y-3.59	0.9429 ***	0.889
WL-711	Y= 0.75X+3.84 X= 1.11Y-2.34	0.9177 ***	0.8423
SONALIKA	Y= 0.72X+4.06 X= 1.09Y-1.83	0.8884 ***	0.7892
MIXED	Y= 0.83X+3.01 X= 1.03Y-1.37	0.9281 ***	0.8614

*** $p < 0.001$

3.1.5 Black Digital model TDI, OGA moisture meter:

Table 7 shows the regression equations and the correlations. For all varieties correlation coefficiants were highly significant ($p<0.001$), ranging from 0.9913 to 0.9986. Thus, after Kett Riceter-L this meter showed the highest levels of correlations. Dickey John meter showed slightly lesser levels of correlation coefficients than did Black Digital - TD1 moisture tester. Figs. 6a - 6h show the calibrations.

Table-7. The relationships between readings of Black Digital TD-1(OGA) Moisture Meter and Moisture Content as determined by Oven Standard Method.

VARIETY	Regression Equation for OGA TD-1 moisture meter(Y) to Oven Standard Method(X).	Correlation Coefficient(r)	Coefficient of Determination(r2)
PAK-81	Y= 1.05X-0.38 X= 0.93Y+0.46	0.996 ***	0.9921
BLUE SILVER	Y= 1.22X-2.22 X= 0.80Y+1.88	0.9966 ***	0.9933
PAVAN	Y= 1.30X-2.95 X= 0.76Y+2.33	0.9964 ***	0.9929
PUNJAB-81	Y= 1.08X-0.46 X= 0.90Y+0.64	0.9913 ***	0.9827
LU-26	Y= 1.18X-1.95 X= 0.83Y+1.79	0.9936 ***	0.9874
WL-711	Y= 1.23X-2.52 X= 0.80Y+2.11	0.9957 ***	0.9914
SONALIKA	Y= 1.12X-1.47 X= 0.88Y+1.34	0.9986 ***	0.9972
MIXED	Y= 1.14X-1.28 X= 0.86Y+1.27	0.9936 ***	0.9872

*** p (0.001

3.2 PRECISION OF MOISTURE METERS AGAINST OVEN STANDARD METHOD.

The precision of various moisture meters tested varied significantly with the wheat varieties as well as with the different ranges of moisture content. This is owing to the fact that different varieites vary in their chemical constituents and thus effect the flow of charges as pointed out in Section 1 of this report. The details pertaining to accuracy of the different moisture meters at different moisture content ranges in different varieties are summarized in Table 8. Some of the details for various moisture instruments in this context are discussed below:

Table-8. Moisture Meters accuracy ranges against Oven Standard Method for various wheat varieties.

Moisture Meters	Varieties							
	PAK-81	Blue Silver	Pavan	Punjab-81	LU-26	WL-711	Sonalika	Mixed
Burrows: digital-700 moisture computer	11 - 12 (0.0-0.5)	13 - 15 (0.1-0.2)	10 - 12 (0.5)	11 - 14 (0.0-0.3)	11 - 14 (0.1-0.5)	16 - 19 (0.1-0.3)	9 - 12 (0.2-0.3)	9 - 11 (0.5)
Protimeter Grain Master	*	*	*	*	*	*	*	*
Kett Riceter-L.	10 - 13 (0.0-0.1)	10 - 13 (0.1-0.2)	10 - 13 (0.1-0.2)	10 - 12.5 (0.4-0.5)	10 - 13 (0.2-0.3)	10 - 12 (0.1-0.4)	10 - 12 (0.1-0.2)	10 - 12 (0.1-0.3)
Dickey John. DJGMT	12 - 13 (0.2-0.4)	11 - 15 (0.0-0.2)	9 - 14 (0.5)	9 - 12 (0.1-0.3)	11 - 12 (0.4-0.5)	13 - 16 (0.1-0.4)	12 (0.1)	12 - 14 (0.1-0.5)
Dole-500.	14 - 17 (0.1-0.4)	16 - 18 (0.1-0.3)	13 (0.1)	13 - 15 (0.2-0.5)	15 - 17 (0.0-0.2)	15 - 17 (0.0-0.3)	14 - 17 (0.0-0.5)	16 - 19 (0.2-0.4)
Black Digital, TD-1(DGA)	10 - 12 (0.1-0.3)	10 - 12 (0.4-0.7)	9 - 11 (0.5)	9 - 11 (0.5)	10 - 13 (0.1-0.2)	10 - 11 (0.2-0.5)	10 - 13 (0.1-0.2)	10 - 12 (0.3-0.4)

3.2.1 Burrows digital- 700 moisture computer:

At lower range (below 12%) this meter gave an accuracy of 0.1 to 0.3% for Punjab-81 and Sonalika varieties whereas generally speaking the accuracy was 0.5% for rest of the varieties in this range. Within a high moisture range (12 to 15%) the accuracy was higher for most of the varieties tested. This capacitance type of moisture meter appeared to be a good choice for wheat with relatively higher moisture content (12 to 15%) for most of the prevalent varieties. However, due to its size and weight the meter is not portable and can be used for laboratory purposes after appropriate calibration. One of the problem of capacitance type of moisture meter i.e, differences in packing of grain is to some extent overcome by a built-in scale.

3.2.2 Protimeter - grain master:

Although the correlation coefficients for the readings of this meter with those of oven standards were significant, the meter consistently over-estimated the moisture content by 2-4% for different varieties. This is an old moisture meter type and currently its use is abondoned in most laboratories.

3.2.3 Kett Riceter-L moisture meter:

It is portable type moisture meter which can be used for determining the moisture content for various cereals. The moisture content is displayed in a digital readout. It can also give an average value of replications. This moisture meter type was found to be the most accurate among the various meters tested for the various varieties. The accuracy range for all the varieties except Punjab-81 was mostly in the range of 0.1 to 0.3% at different moisture levels. Thus, this meter can safely be used for general purposes.

3.2.4 Dickey John model DJGMT moisture meter:

This moisture meter is frequently used for determining moisture content of corn. Conversion tables are available for other cereals. However, in the present study moisture measurements were made directly without using the manufacturer's conversion tables and calibrations were made with the oven standard. The meter is of capacitance type and was found accurate for Punjab-81 within the moisture range of 9-12% (accuracy 0.1-0.3%). For Sonalika at 12% moisture content the accuracy was 0.1%. Generally speaking the moisture meter gives to an extent close resluts in the median range for most of the varieties. Under the Pakistani conditions where there is no concept of distinction of varieties and the moisture content is generally low this meter can not be preferred over some other meters.

3.2.5 Dole -500 moisture meter:

It is a small handly type of moisture meter of capacitance type which is only accurate above 13% moisture content for various wheat varieties. The results have shown that at 13% moisture content, It has a accuracy of 0.1% for Pavan variety. It is therefore, concluded that the meter can only be used with the help of calibration charts for separate varieties under low moisture content conditions. Whereas, at higher moisture contents the accuracy is fairly high against most of the prevalent varieties.

3.2.6 Black Digital TD-1, OGA moisture meter:

This moisture meter is a handy type with easy operation and can be used for determination against various cereals. The moisture meter was provided in large numbers by IDA's World Bank project to the provincial food departments for their routine use. It is a resistance type and the results obtained out of the present study have clearly shown that it can be used safely against a wide range of varieties at low moisture content levels. It is in general more accurate at 10% moisture content against most of the varieties except Blue Silver, Pavan and Punjab-81 where the accuracy is around 0.5%. In order of merit based on several criteria, it stands number two to Kett Riceter-L for general purpose use in the food handling agencies.

4. CONCLUSIONS

On the basis of the results of the experiments, following conclusions are drawn.

1. Under the hot and dry climatic conditions of Pakistan in which the moisture content of wheat is generally low at the procurement season (8-11%), Kett Riceter-L has shown the best results. However, this moisture meter does not display moisture below 10%, which is common with resistance type of moisture meters.

2. Black Digital TD-1 OGA type of moisture meter has an edge over Kett Riceter-L as it can also record the moisture content upto a low limit of 9%. Whereas its accuracy stands next to Kett Riceter-L as for a couple of varieties the accuracy drops to 0.5% at low range.

3. Since the agencies for procurement and subsequent handling of wheat in Pakistan do not heave any concept of variety, therefore, it is advisible to use the above referred meters for general purpose in the food handling agencies.

4. The calibration lines are drawn alongwith their regression equations for various wheat varieties. But in practice these calibrations do not value much for general purpose use as there is no concept of variety in the food handling agencies. However, these can be used effectively for research purposes were the varieties are known and right calibrations are required for each type of moisture meter.

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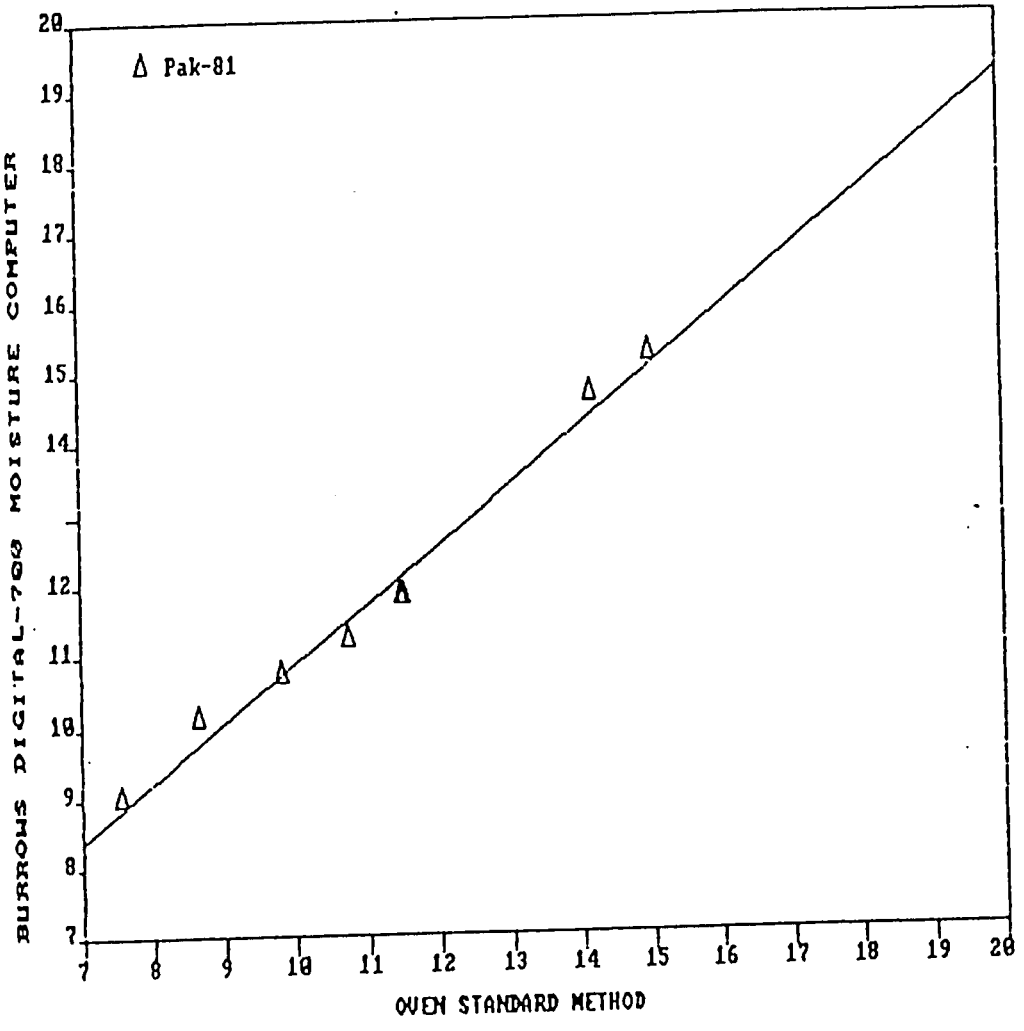
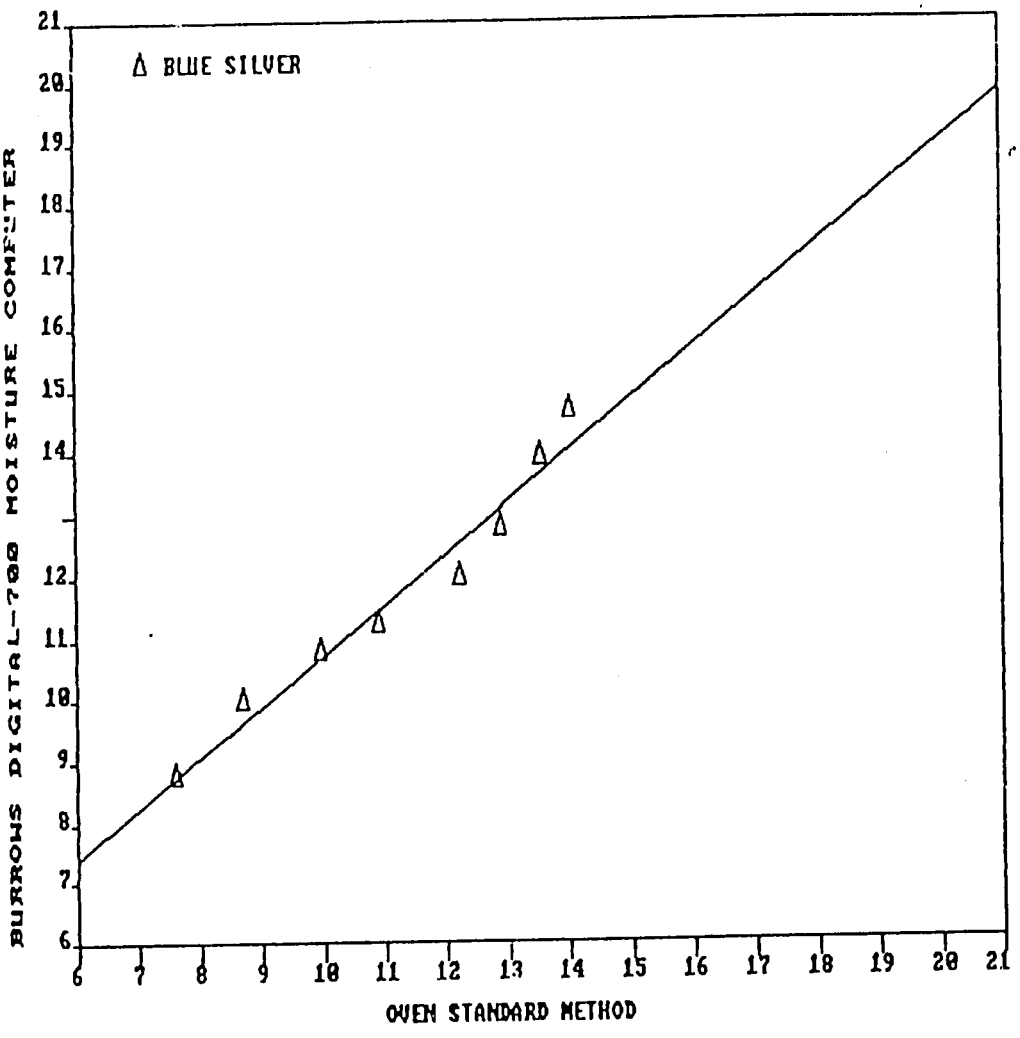
Fig. 1a



THE REGRESSION POLYNOMIAL OF LINE ..

(2.558E+00) + (8.321E-01)*X
THE VARIANCE - 6.425E-02

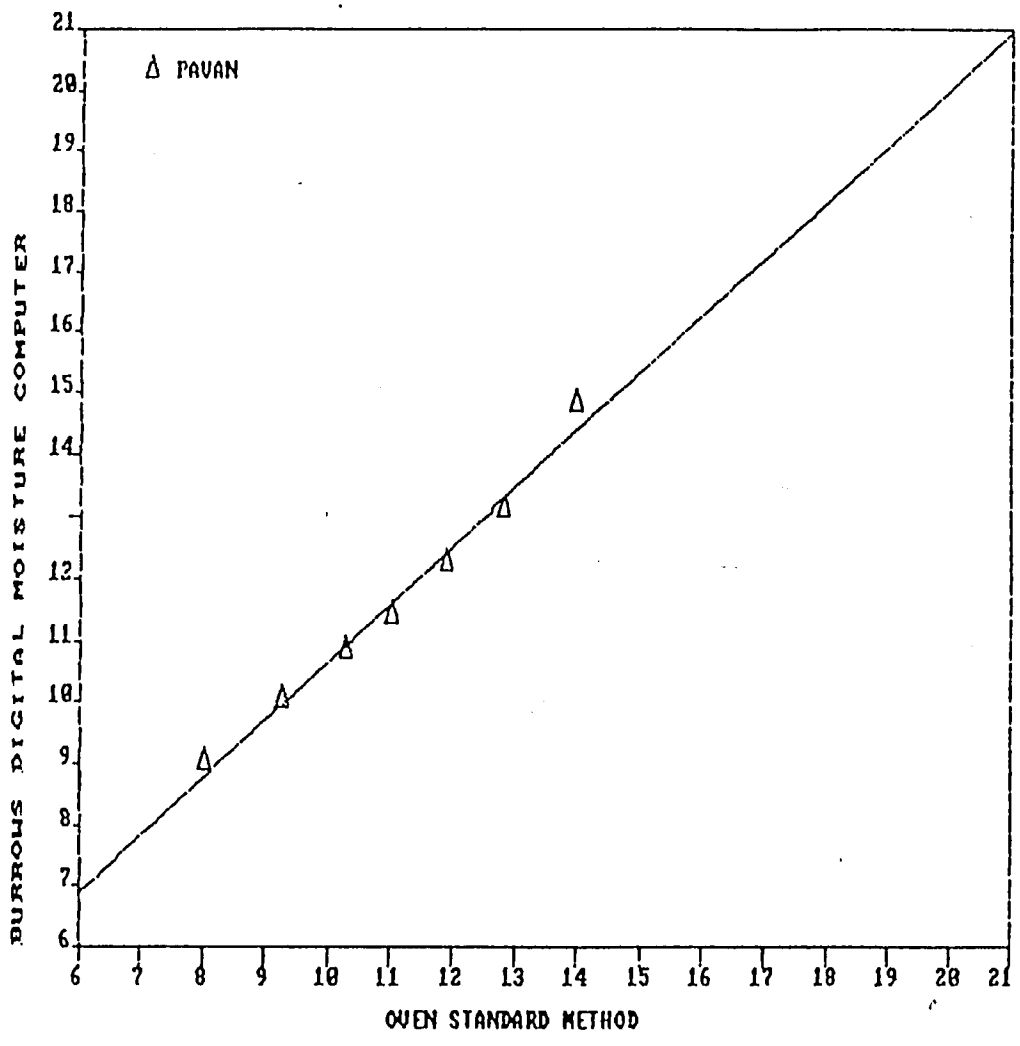
Fig. 1b



THE REGRESSION-POLYNOMIAL OF LINE 1 -

(2.458E+00) + (8.254E-01)*X
THE VARIANCE - 1.281E-01

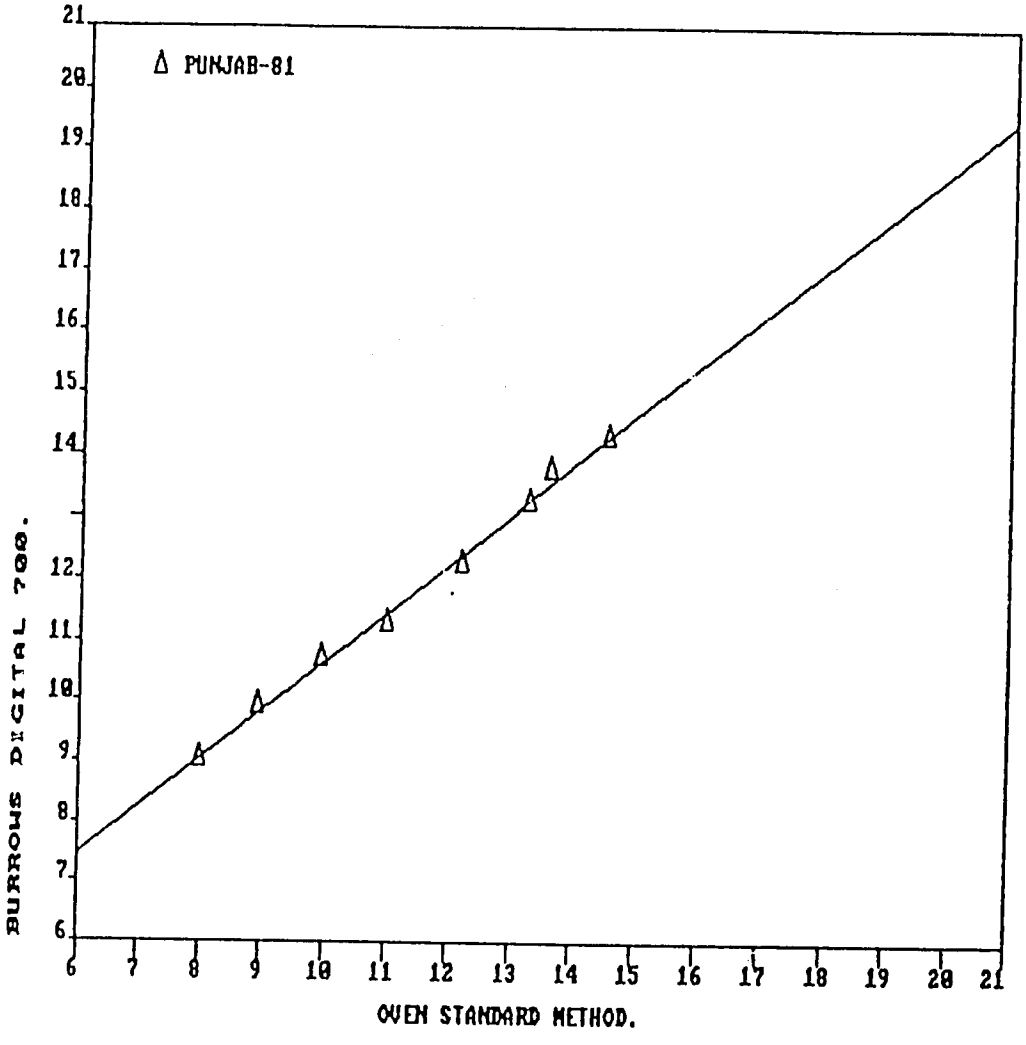
Fig. 1c



THE REGRESSION POLYNOMIAL OF LINE 1 -

(1.260E+00) + (9.380E-01)*X
THE VARIANCE - 4.674E-02

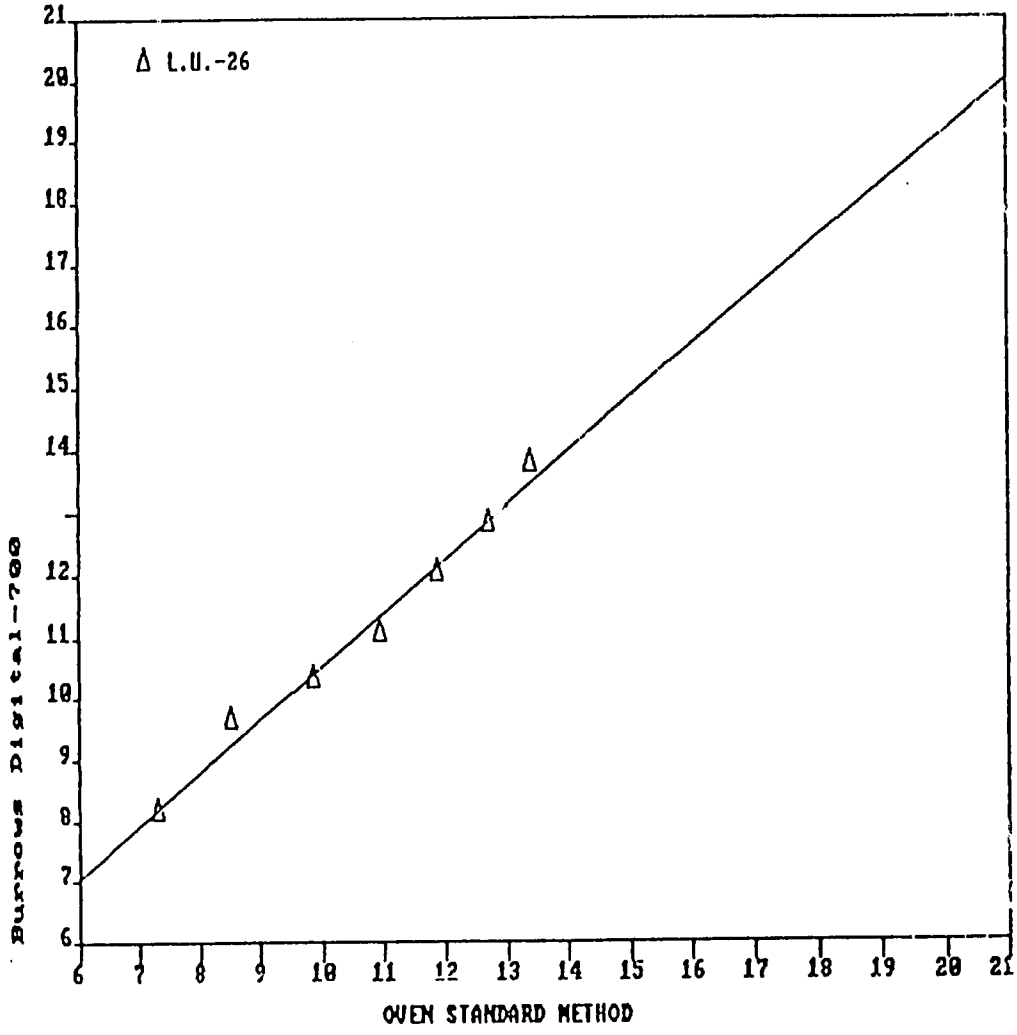
Fig. 1d



THE REGRESSION POLYNOMIAL OF LINE 1 -

(2.643E+00) + (7.999E-01)*X
THE VARIANCE - 1.625E-02

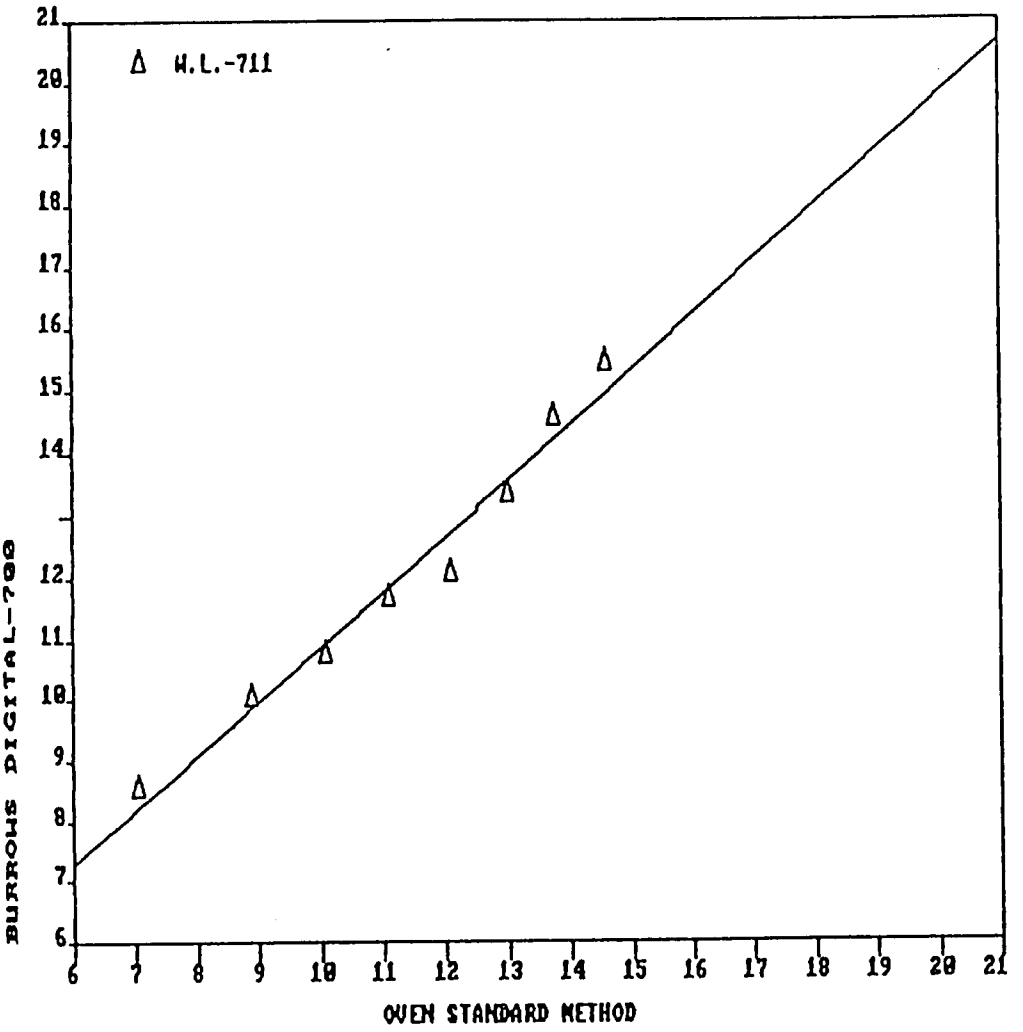
Fig. 1e



THE REGRESSION POLYNOMIAL OF LINE 1 -

(1.922E+00) + (8.596E-01)*X
THE VARIANCE - 4.579E-02

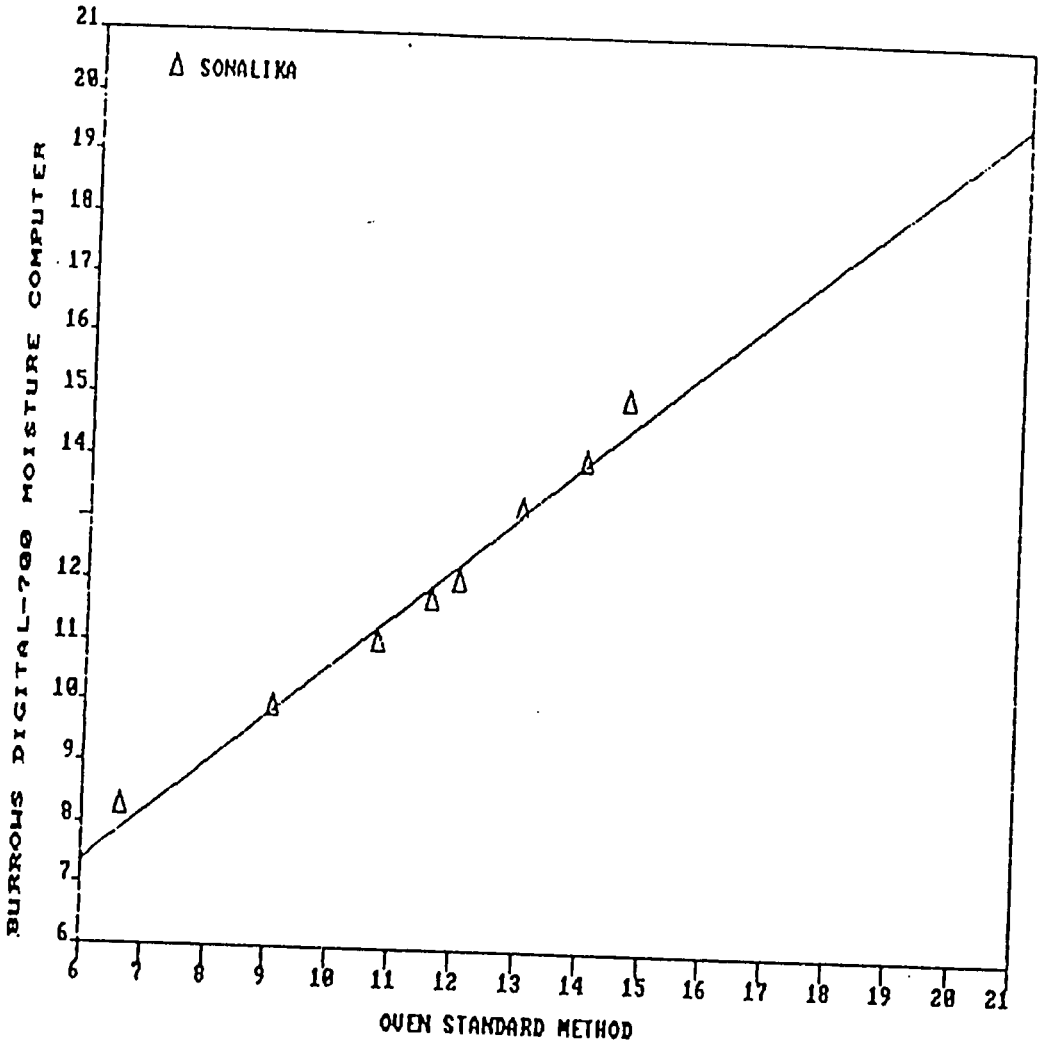
Fig. 1f



THE REGRESSION POLYNOMIAL OF LINE 1 -

(1.900E+00) + (8.938E-01)*X
THE VARIANCE - 1.217E-01

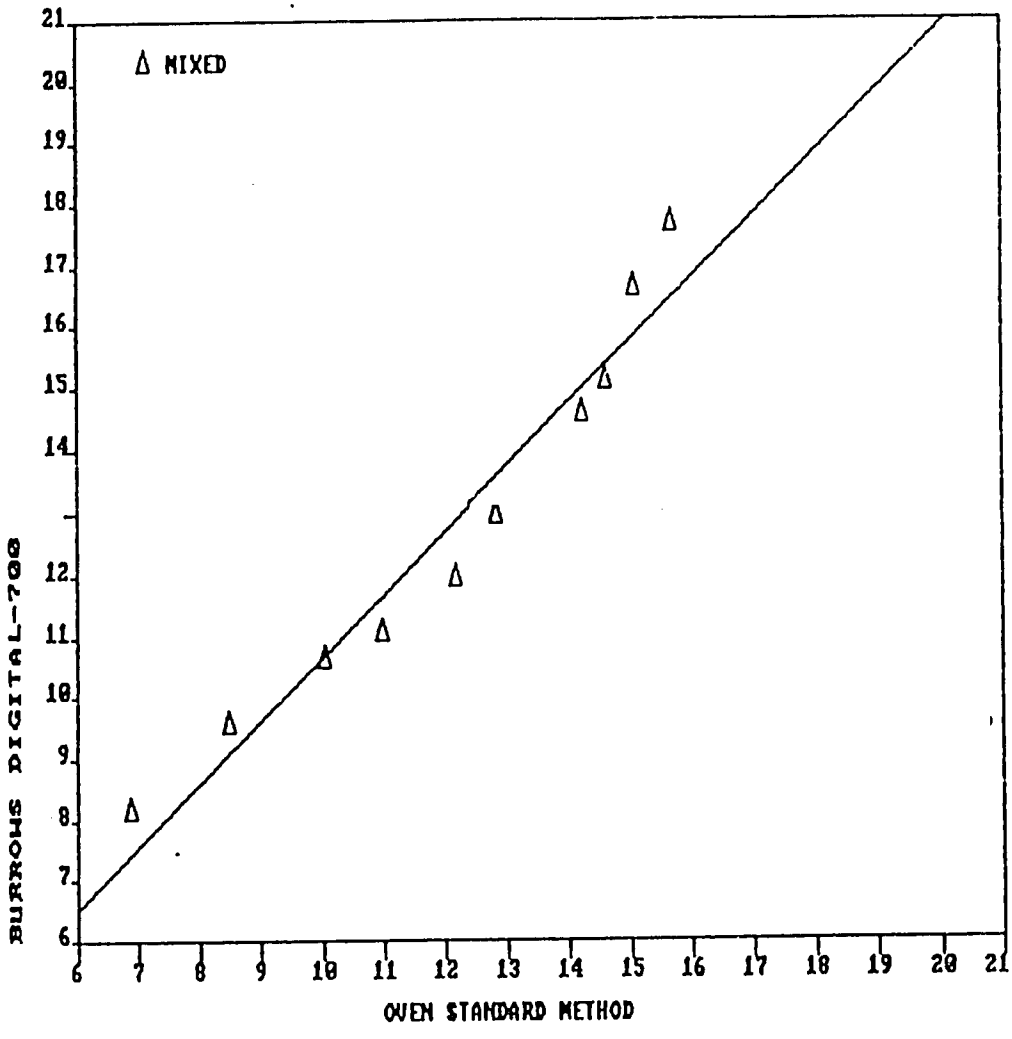
Fig. 1g



THE REGRESSION POLYNOMIAL OF LINE 1 -

(2.456E+00) + (8.215E-01)*X
THE VARIANCE - 7.024E-02

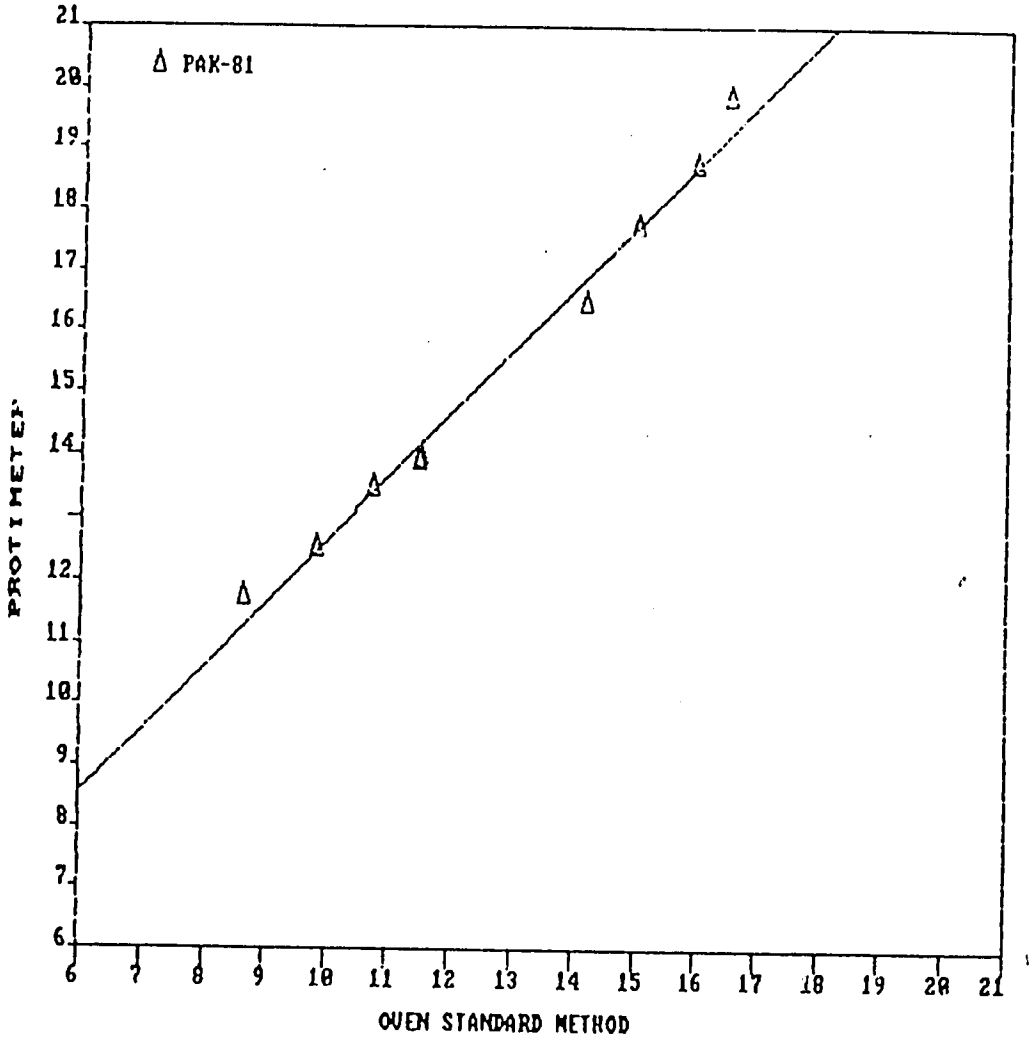
Fig. 1b



THE REGRESSION POLYNOMIAL OF LINE 1 -

(4.051E-01) + (1.024E+00)*X
THE VARIANCE - 4.631E-01

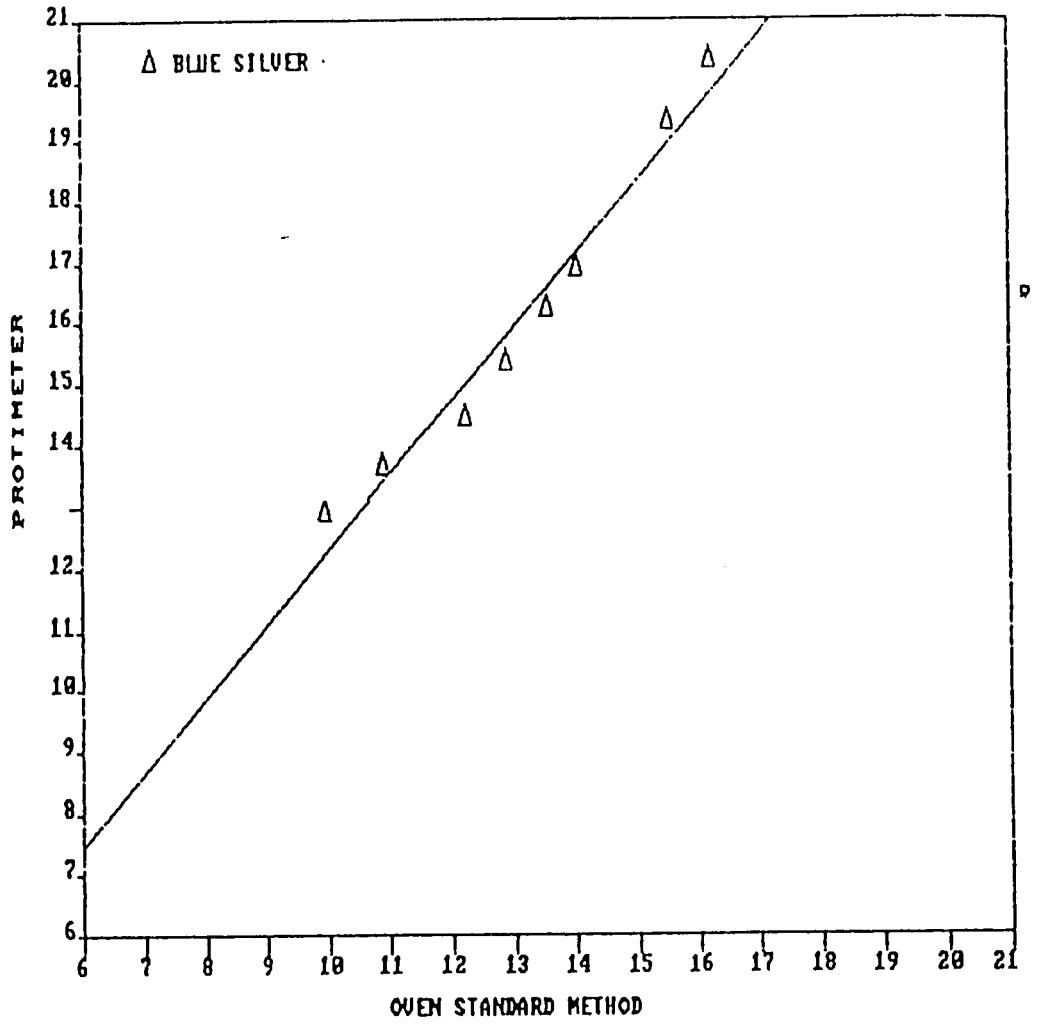
Fig. 2a



THE REGRESSION POLYNOMIAL OF LINE 1 -

(2.428E+00) + (1.021E+00)*X
THE VARIANCE - 9.619E-02

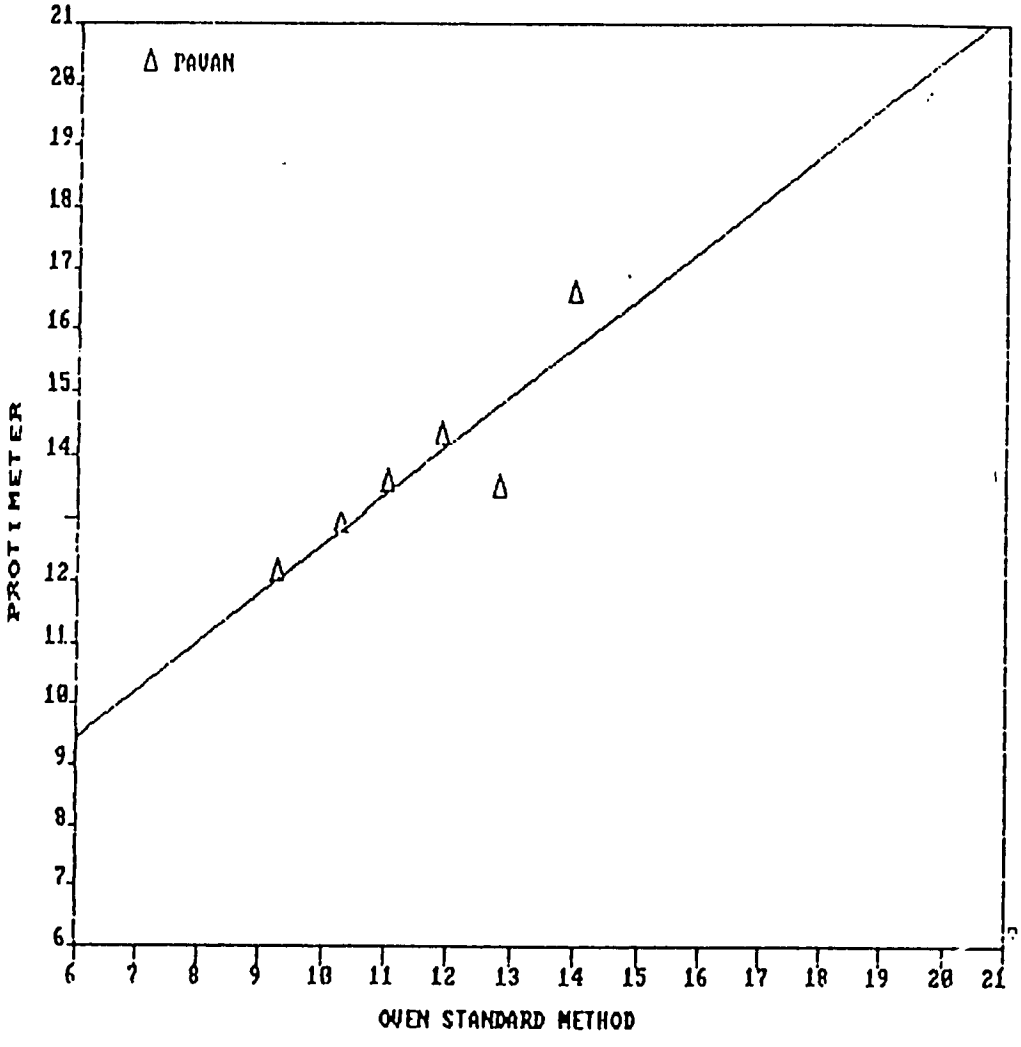
Fig. 2b



THE REGRESSION POLYNOMIAL OF LINE 1 -

(2.245E-01) + (1.207E+00)*X
THE VARIANCE - 2.084E-01

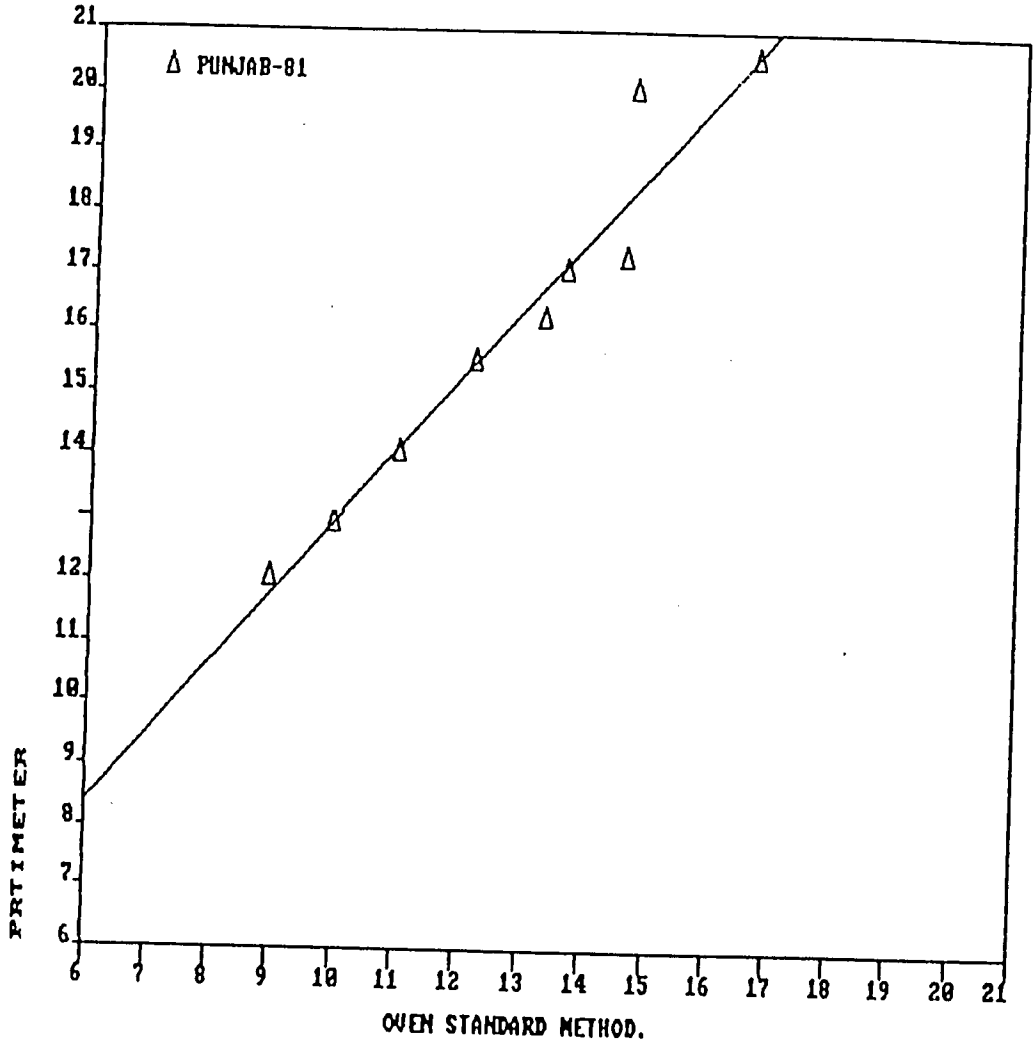
Fig. 2c



THE REGRESSION POLYNOMIAL OF LINE 1 -

(4.731E+00) + (7.847E-01)*X
THE VARIANCE - 4.301E-01

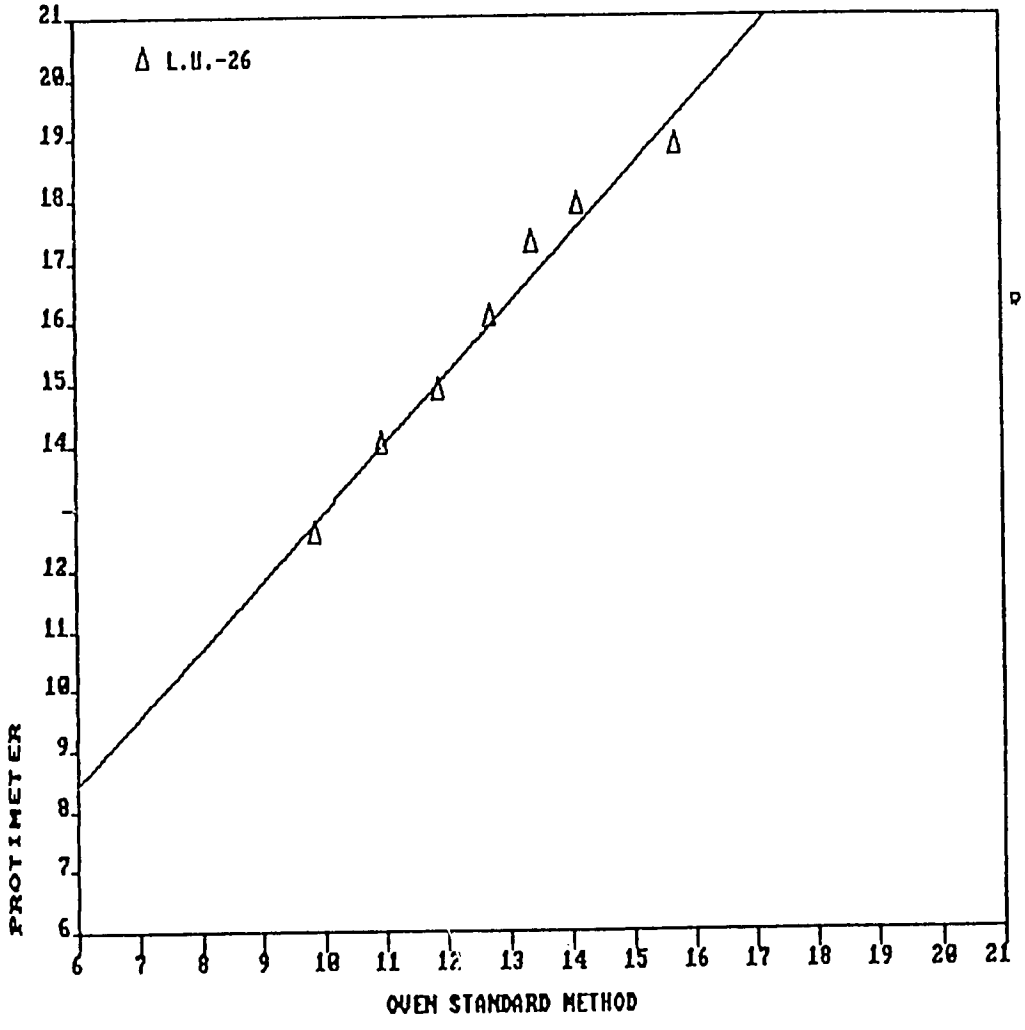
Fig. 2d



THE REGRESSION POLYNOMIAL OF LINE 1 -

(1.502E+00) + (1.150E+00)*X
THE VARIANCE - 4.634E-01

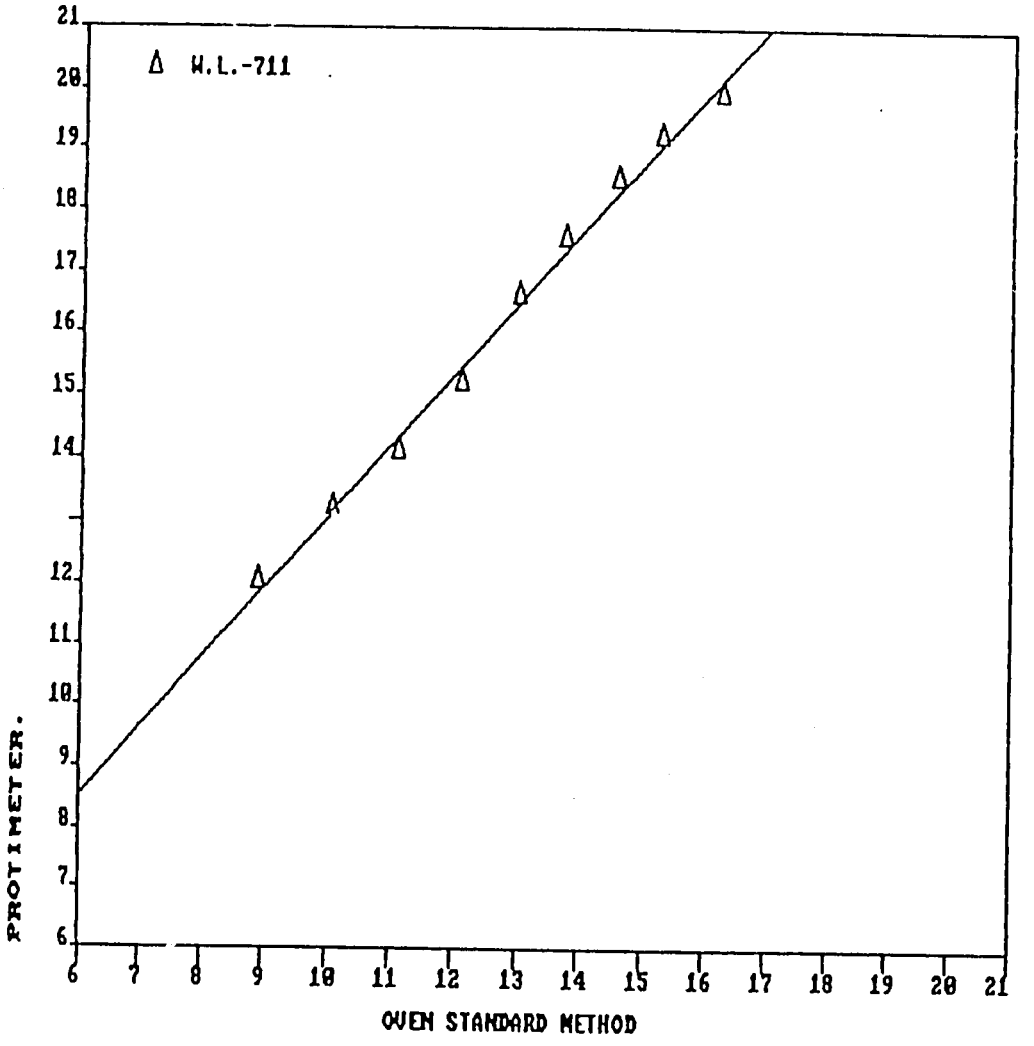
Fig. 2e



THE REGRESSION POLYNOMIAL OF LINE 1

(1.673E+00) + (1.123E+00)*X
THE VARIANCE - 9.839E-02

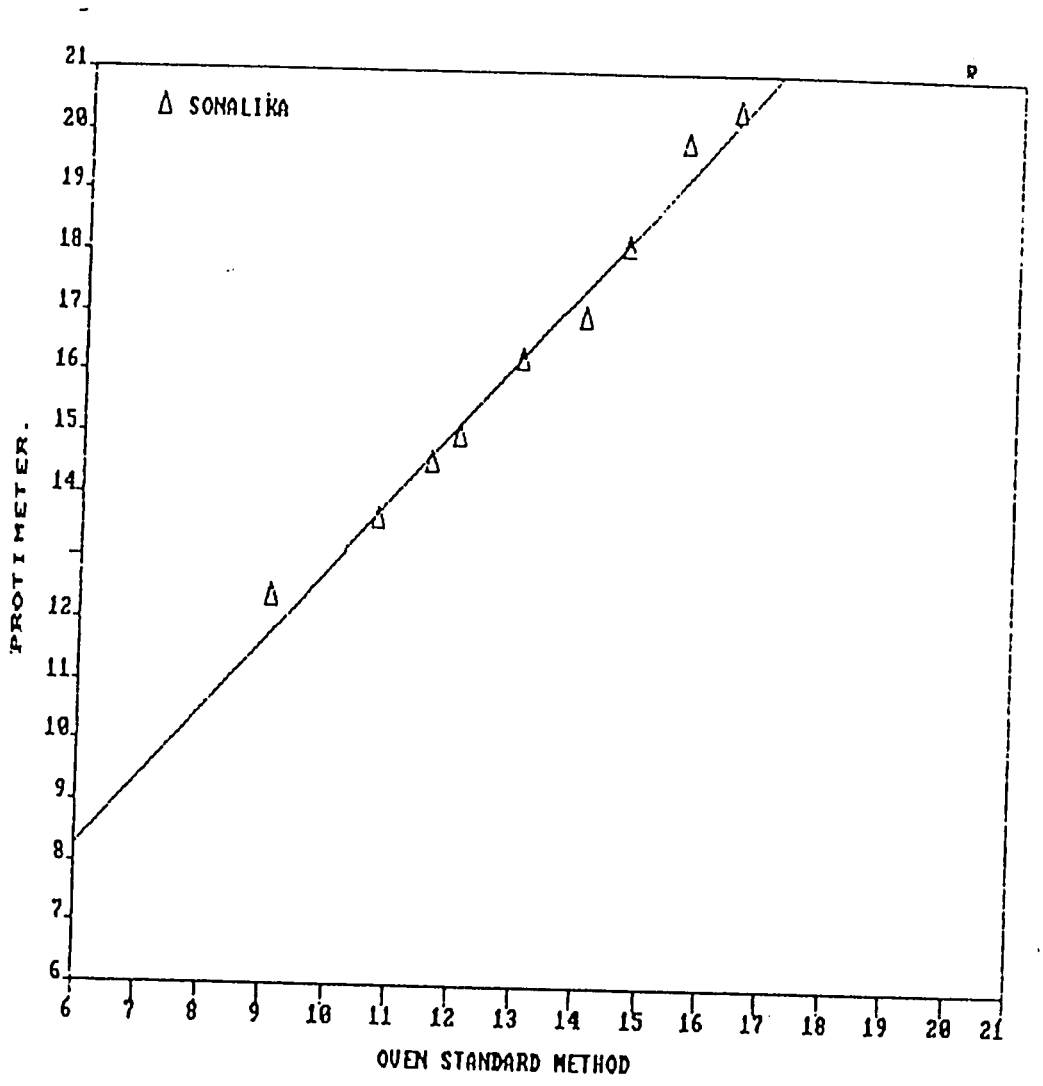
Fig. 2f



THE REGRESSION POLYNOMIAL OF LINE 1 -

(1.717E+00) + (1.136E+00)*X
THE VARIANCE - 4.043E-02

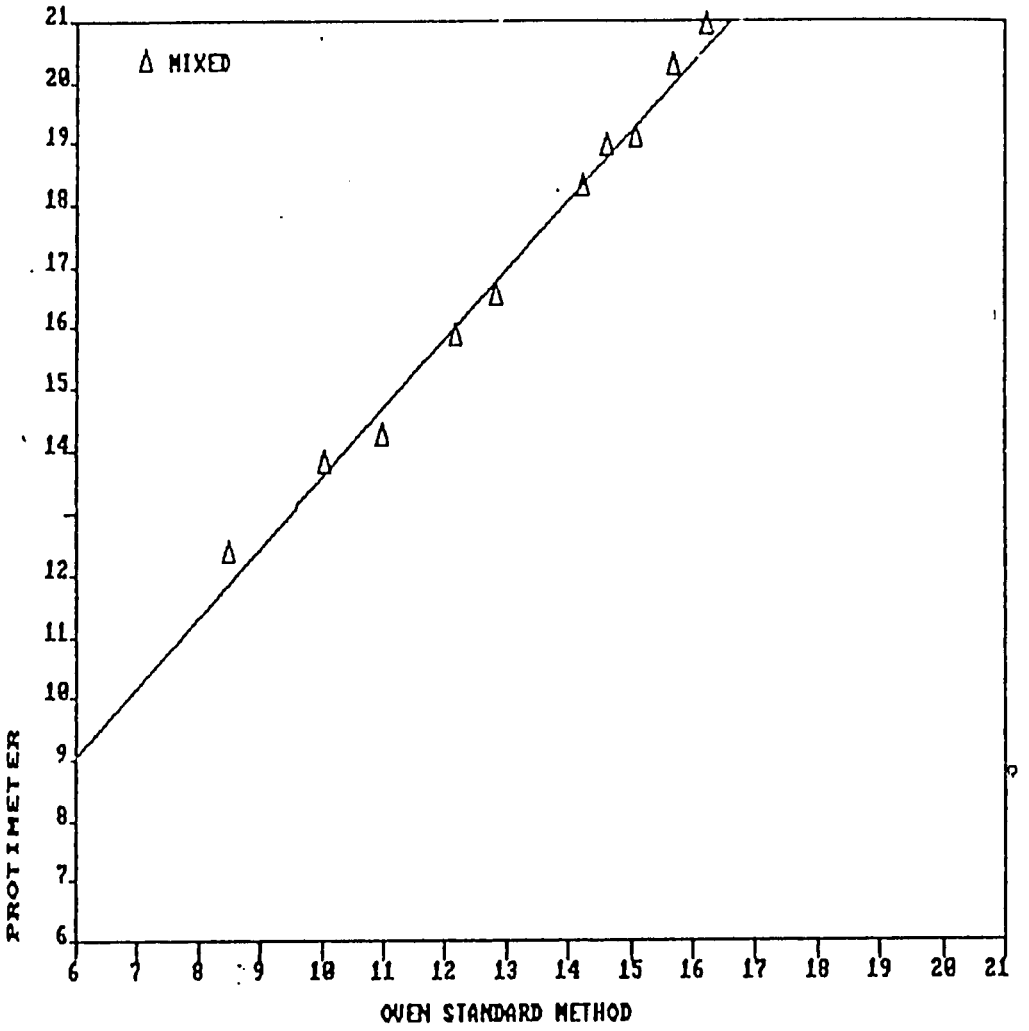
Fig. 2g



THE REGRESSION POLYNOMIAL OF LINE 1 -

(1.353E+00) + (1.150E+00)*X
THE VARIANCE - 1.142E-01

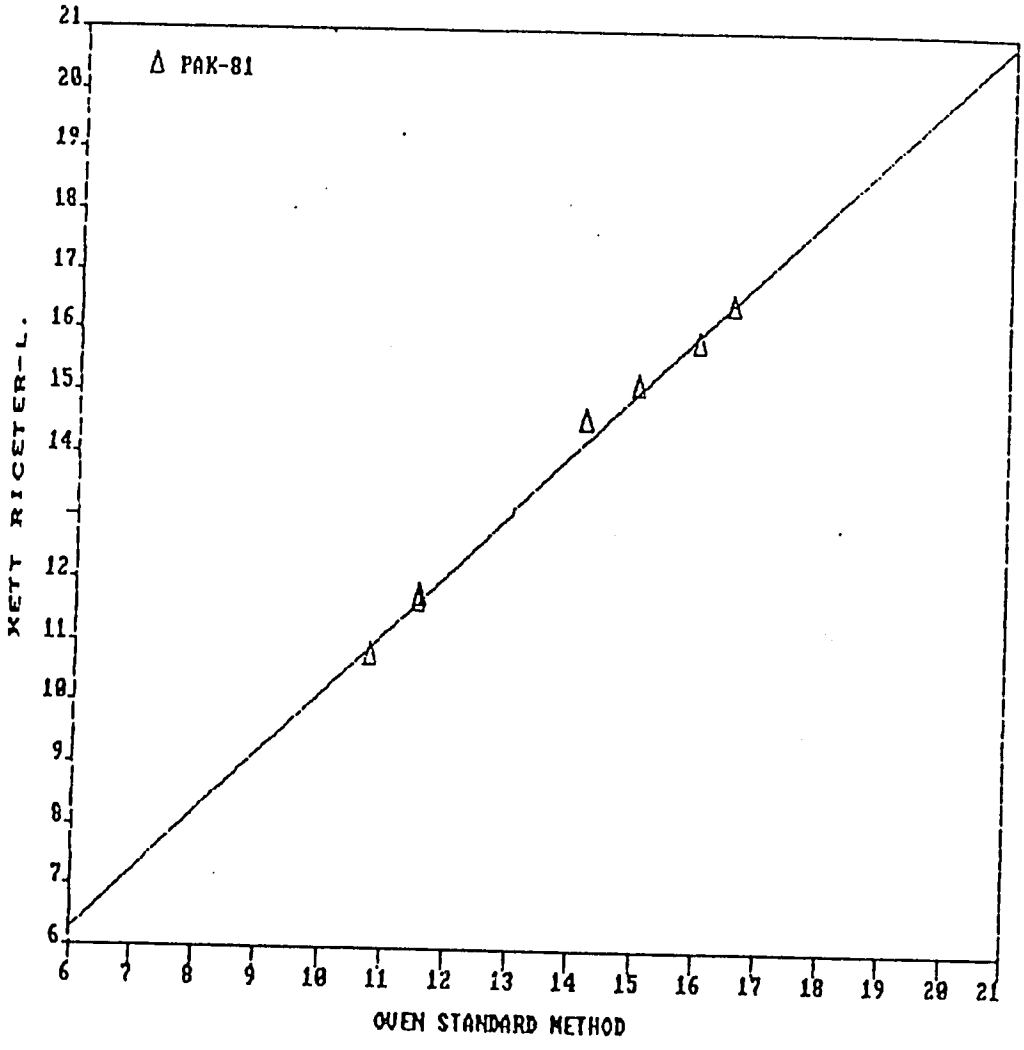
Fig. 2h



THE REGRESSION POLYNOMIAL OF LINE

(2.250E+00) + (1.129E+00)*X
THE VARIANCE - 8.391E-02

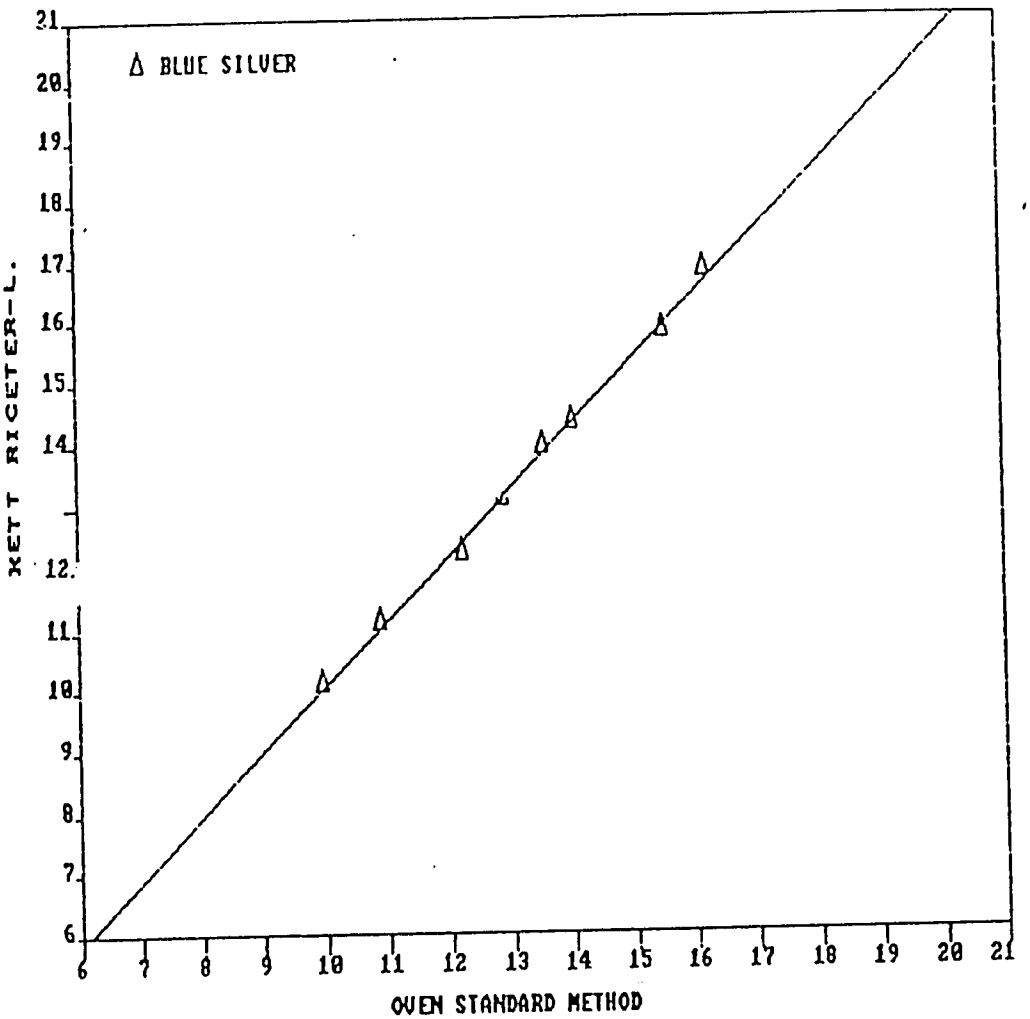
Fig. 3a



THE REGRESSION POLYNOMIAL OF LINE 1 -

(4.135E-01) + (9.749E-01)*X
THE VARIANCE - 2.330E-02

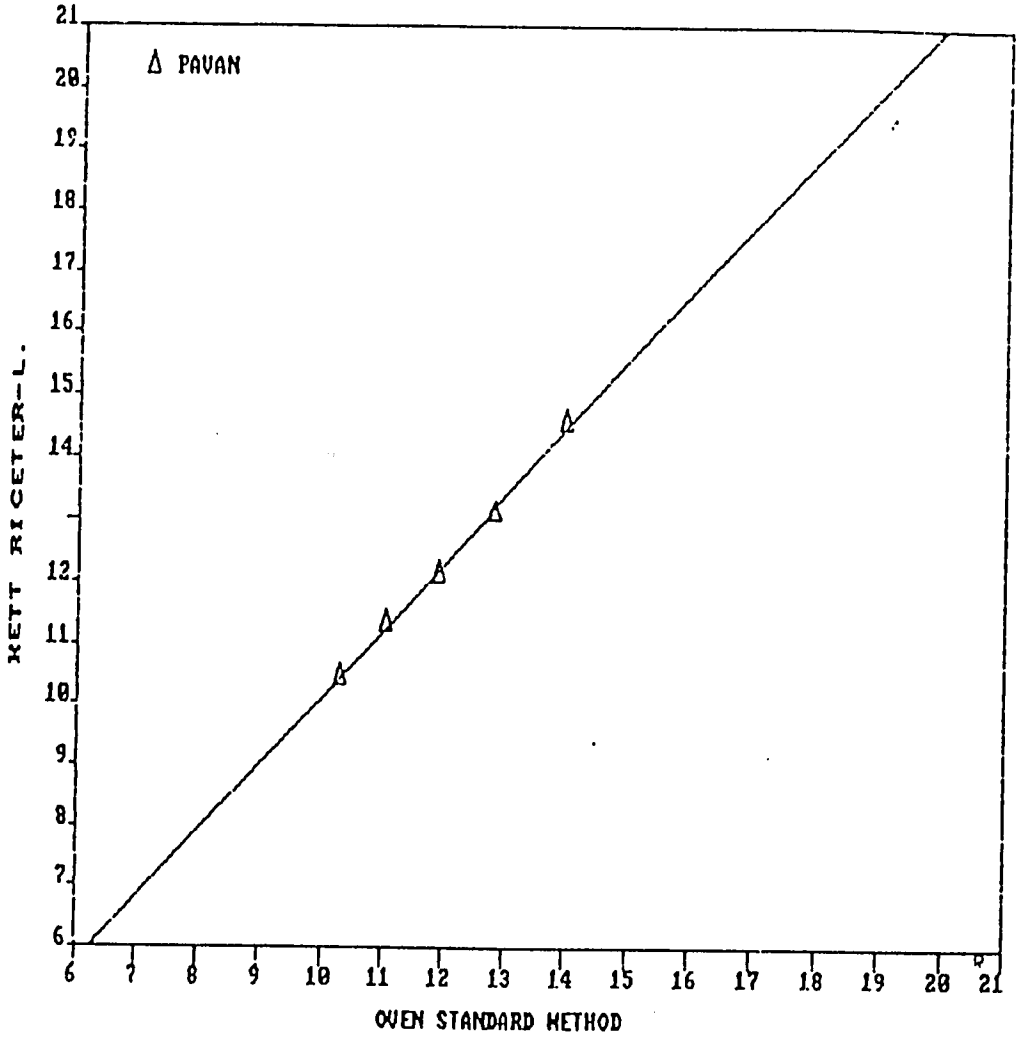
Fig. 3b



THE REGRESSION POLYNOMIAL OF LINE 1 -

(-5.108E-01) + (1.058E+00)*X
THE VARIANCE - 1.376E-02

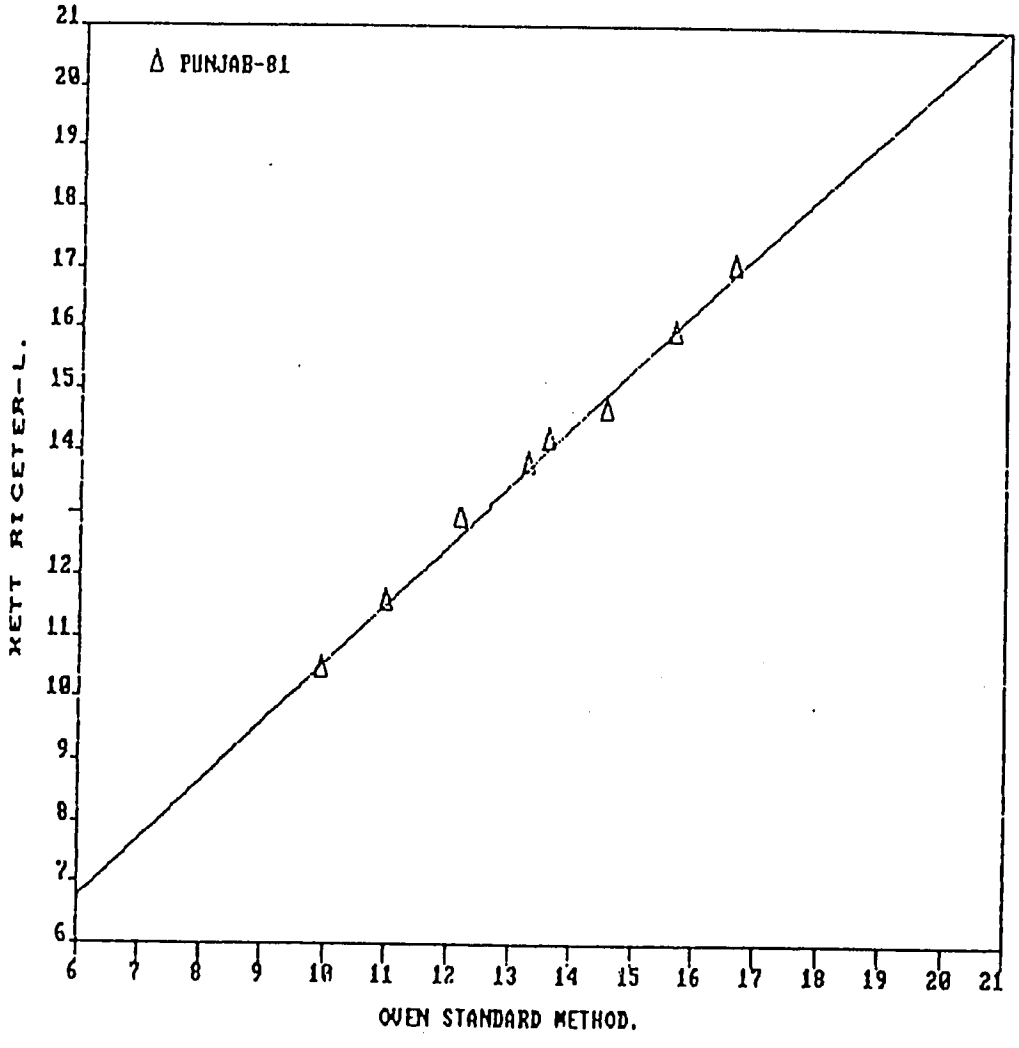
Fig. 3c



THE REGRESSION POLYNOMIAL OF LINE 1 -

(-8.381E-01) + (1.094E+00)*X
THE VARIANCE - 4.101E-03

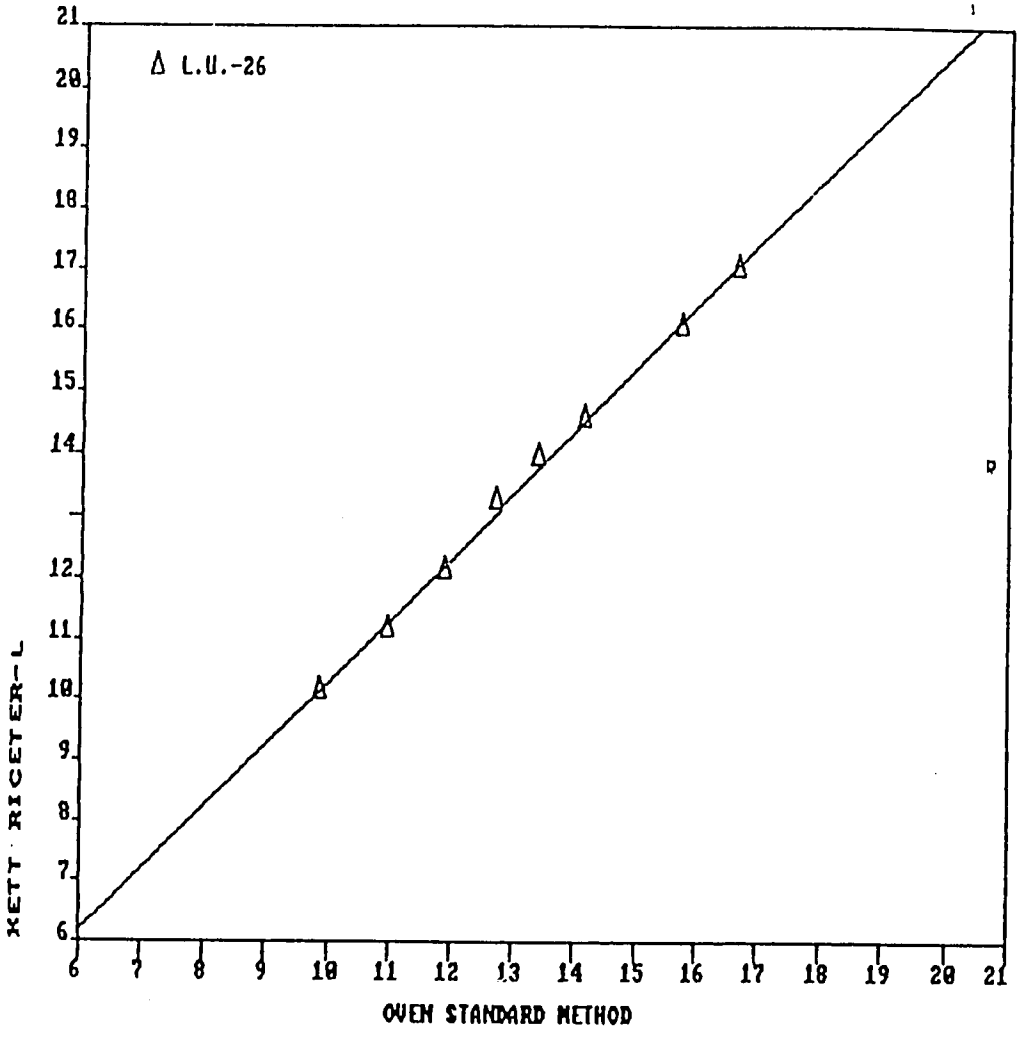
Fig. 3d



THE REGRESSION POLYNOMIAL OF LINE 1 -

(1.030E+00) + (9.548E-01)*X
THE VARIANCE - 2.430E-02

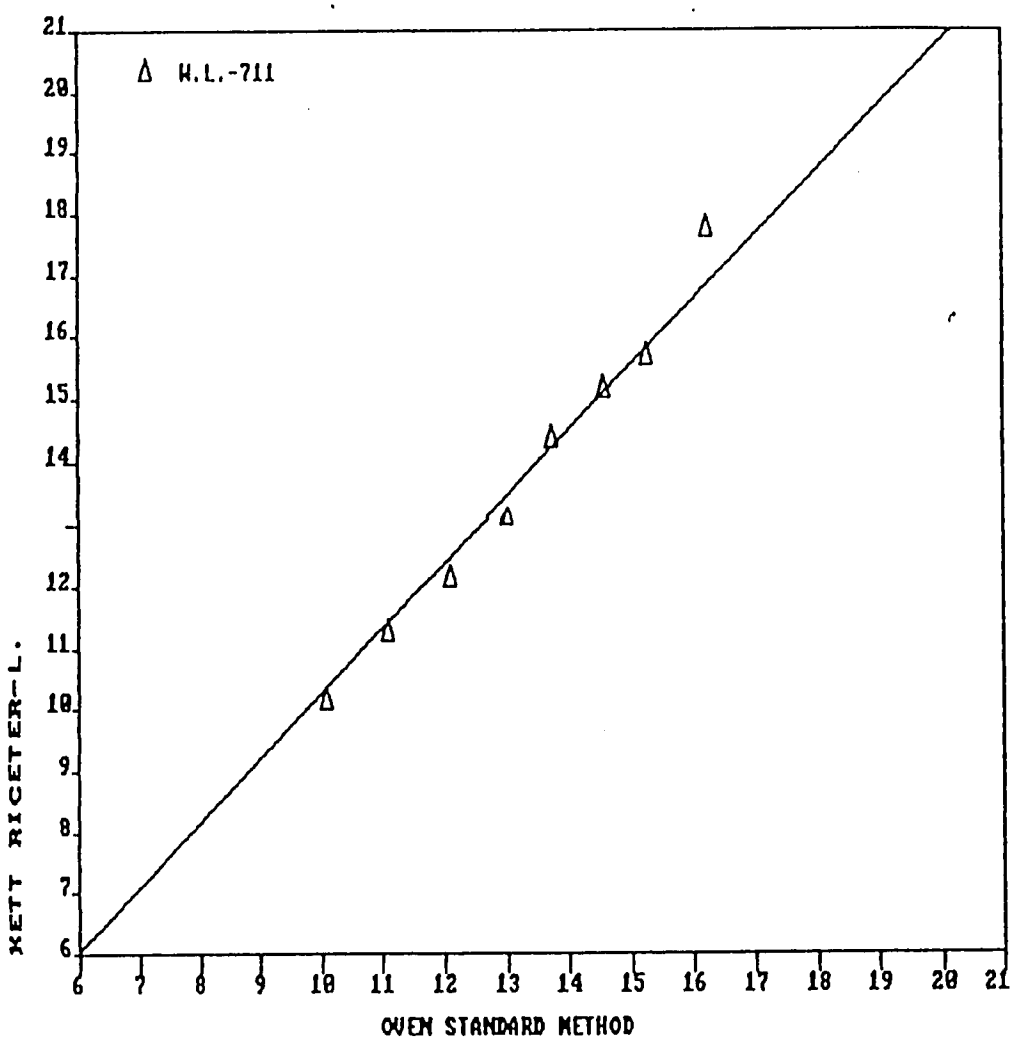
Fig. 3e



THE REGRESSION POLYNOMIAL OF LINE 1 -

(2.762E-02) + (1.023E+00)*X
THE VARIANCE - 1.211E-02

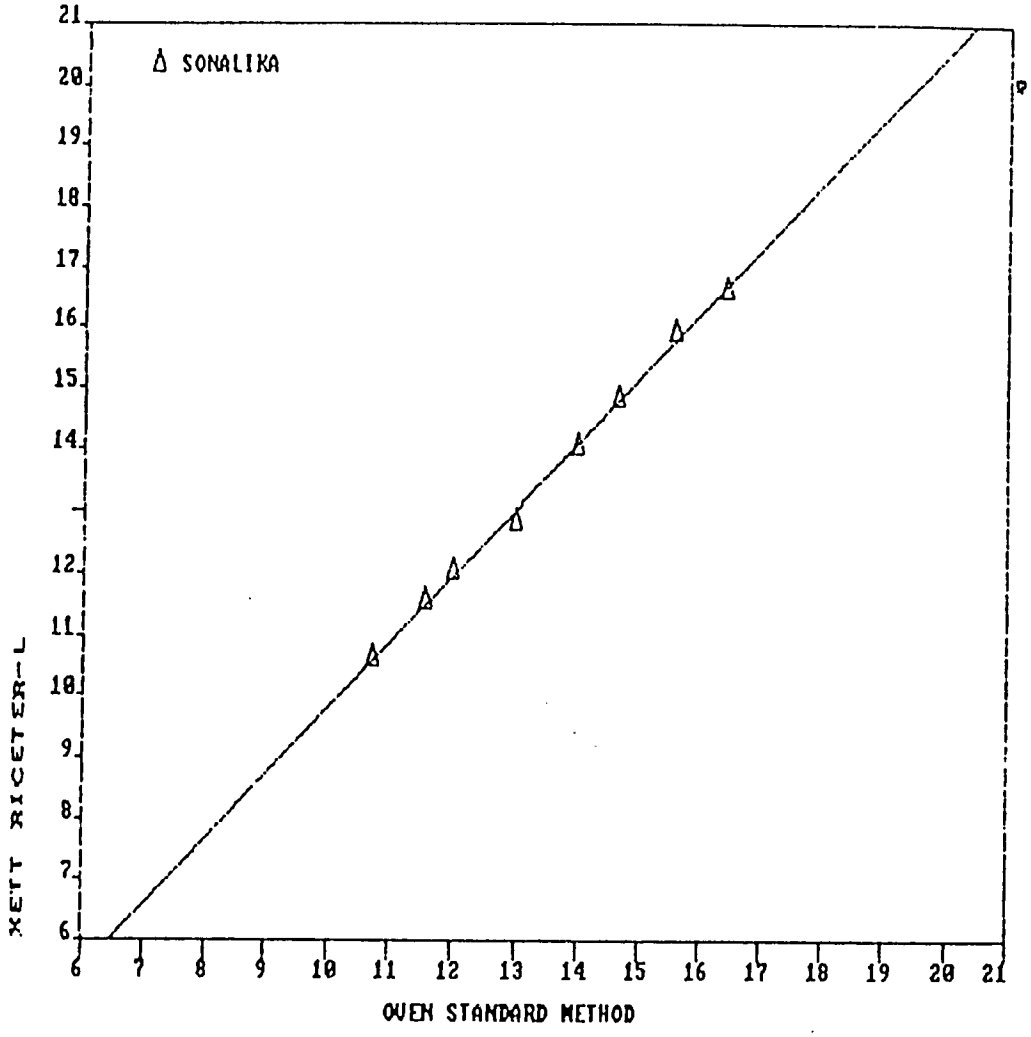
Fig. 3f



THE REGRESSION POLYNOMIAL OF LINE 1 -

(-2.970E-01) + (1.054E+00)*X
THE VARIANCE - 1.358E-01

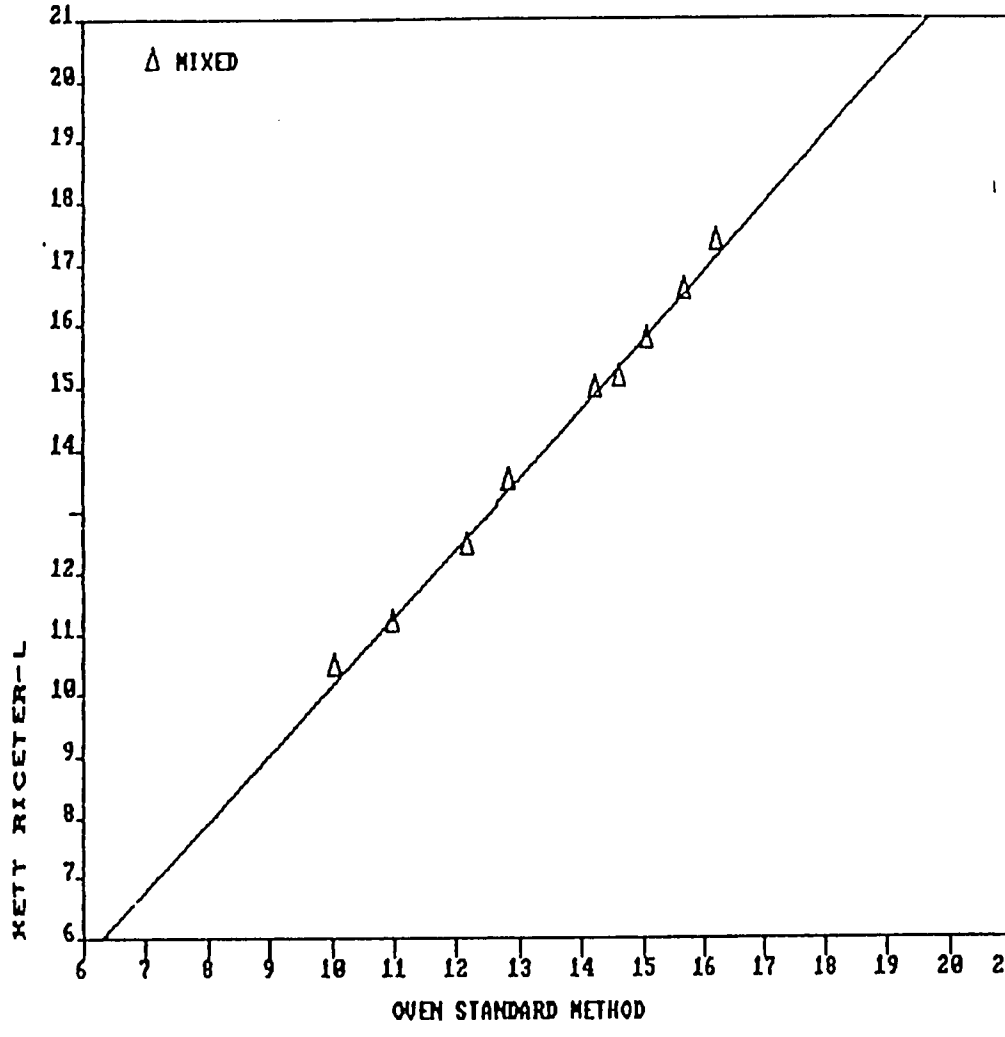
Fig. 3g



THE REGRESSION POLYNOMIAL OF LINE 1 -

(-9.124E-01) + (1.071E+00)*X
THE VARIANCE - 8.519E-03

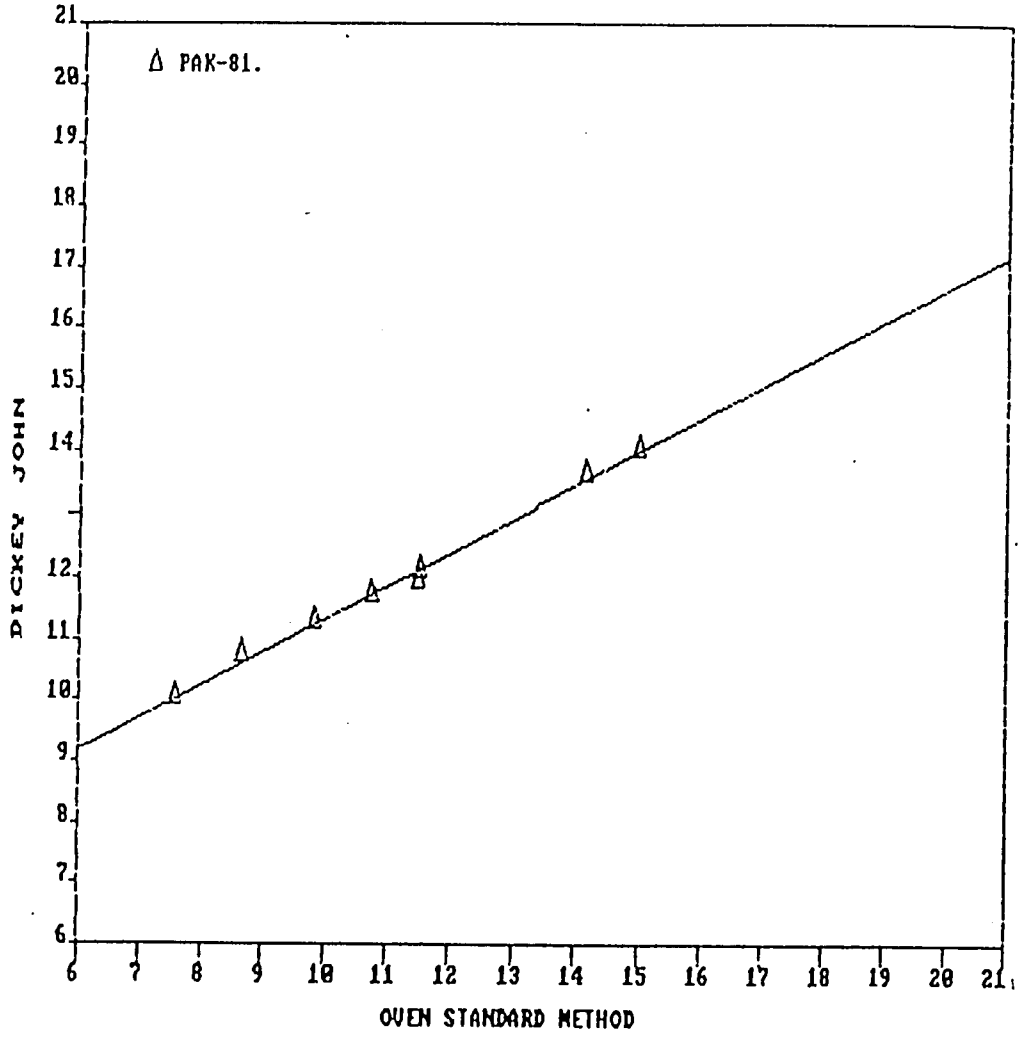
Fig. 3h



THE REGRESSION POLYNOMIAL OF LINE 1 -

(-1.043E+00) + (1.118E+00)*X
THE VARIANCE - 2.199E-02

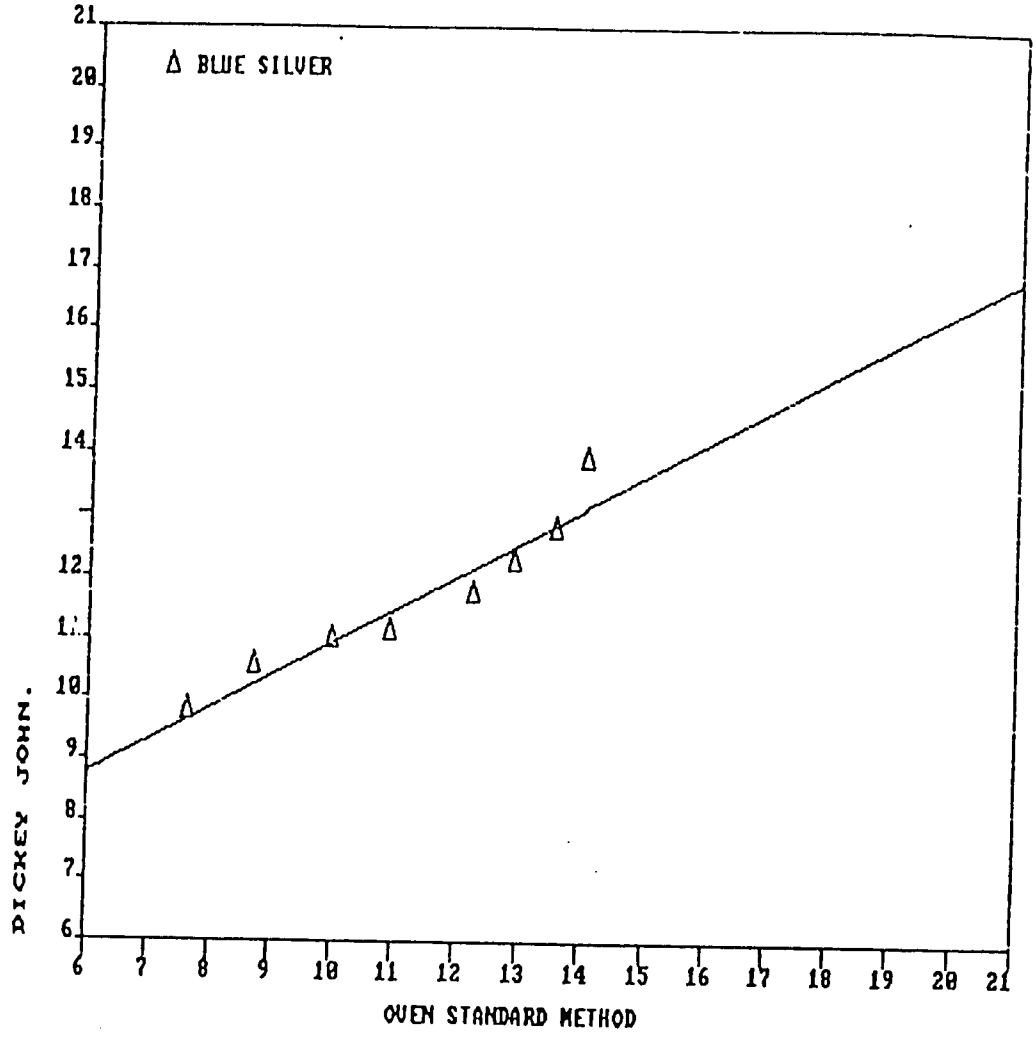
Fig. 4a



THE REGRESSION POLYNOMIAL OF LINE 1 -

(5.997E+00) + (5.319E-01)*X
THE VARIANCE - 8.031E-03

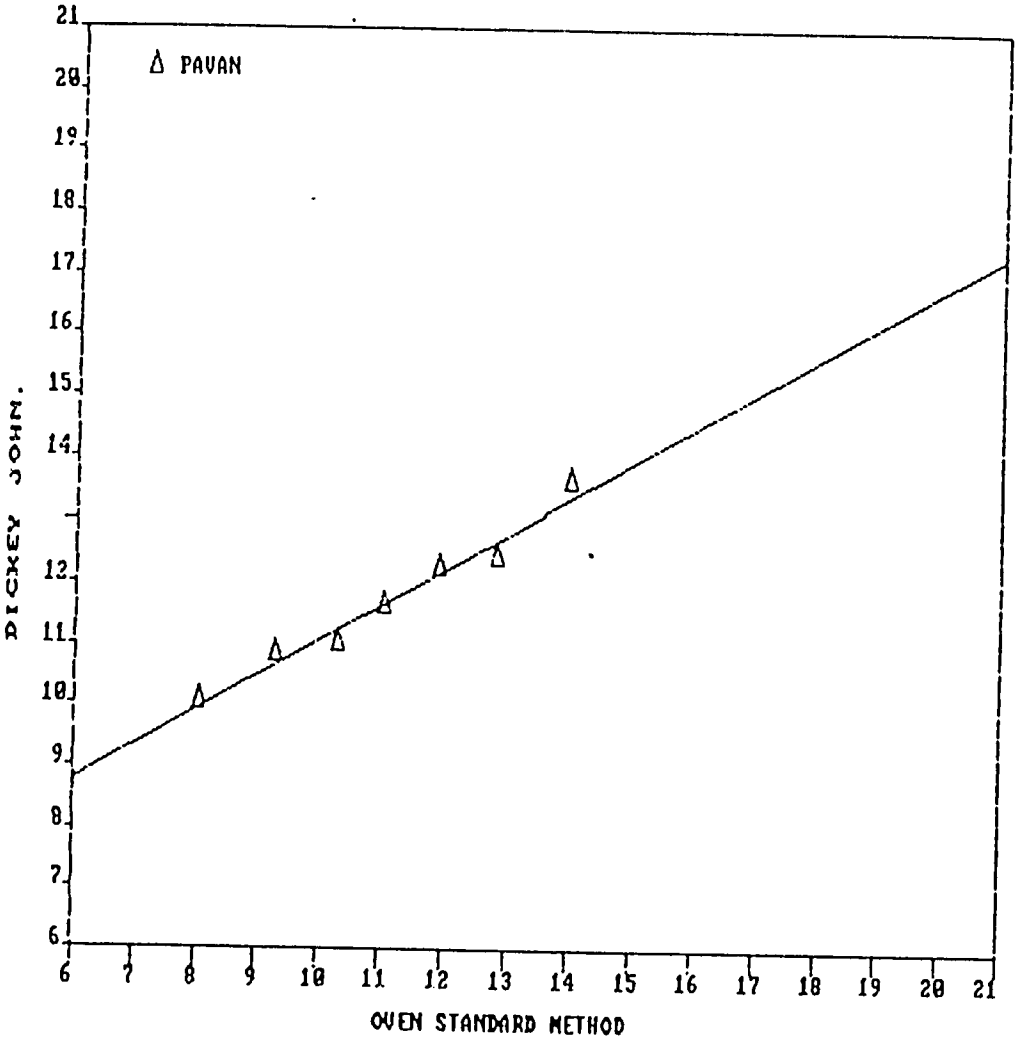
Fig. 4b



THE REGRESSION POLYNOMIAL OF LINE

(5.561E+00) + (5.375E-01)*X
THE VARIANCE - 1.334E-01

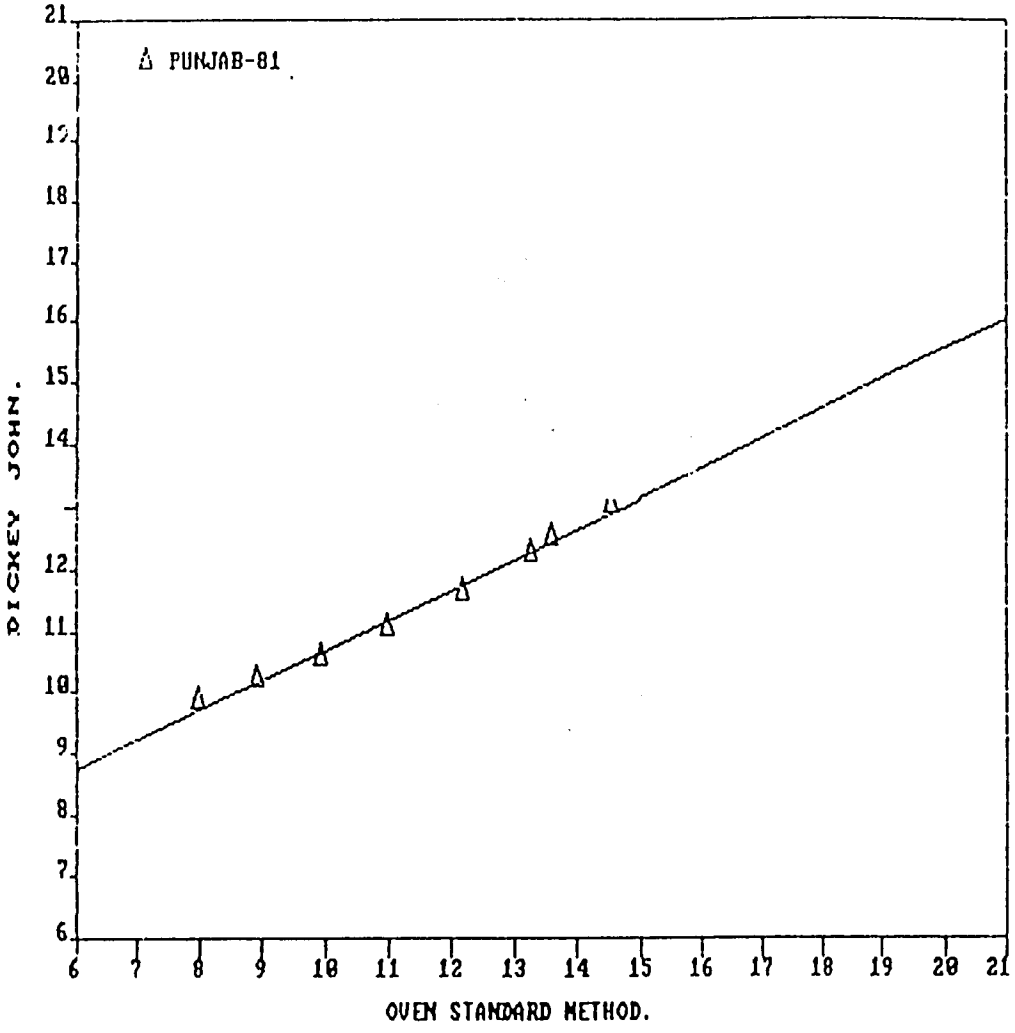
Fig. 4c



THE REGRESSION POLYNOMIAL OF LINE 1 -

(5.361E+00) + (5.712E-01)*X
THE VARIANCE - 3.320E-02

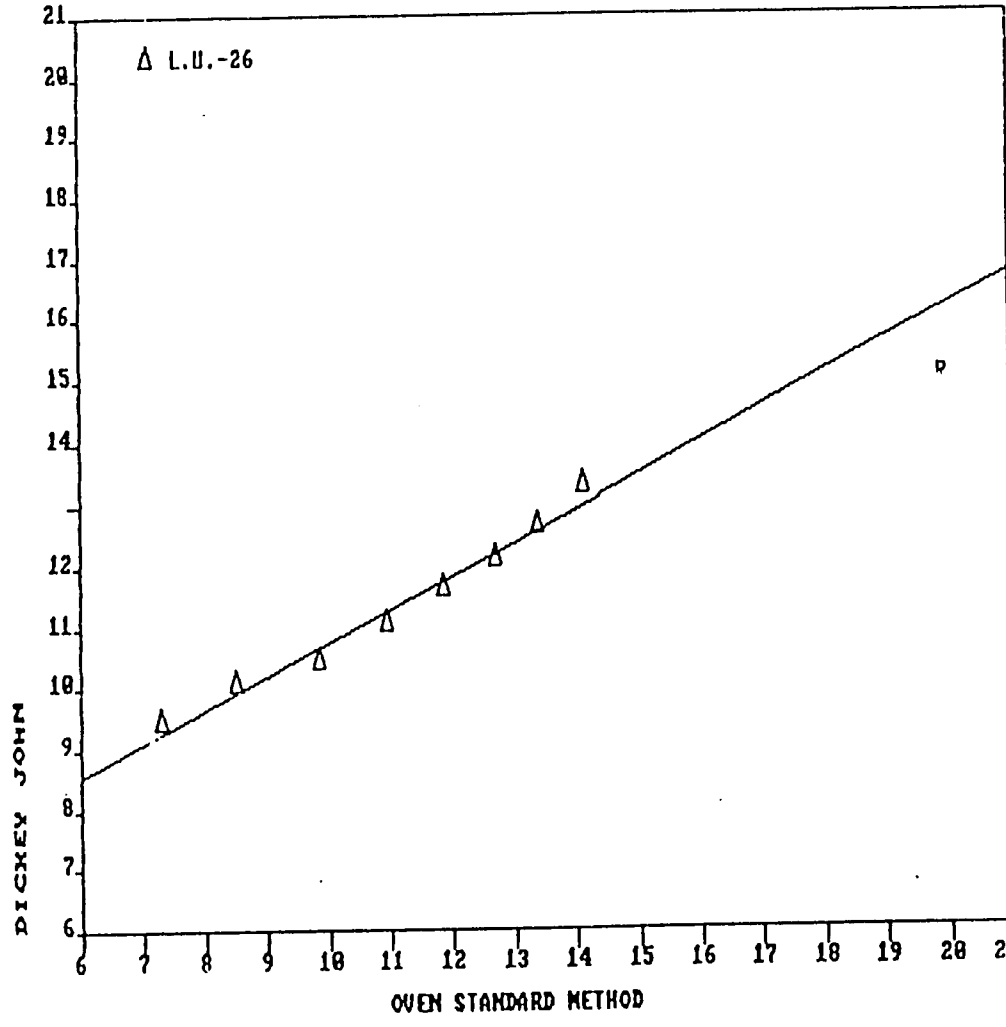
Fig. 4d



THE REGRESSION POLYNOMIAL OF LINE 1 -

(5.809E+00) + (4.870E-01)*X
THE VARIANCE - 1.171E-02

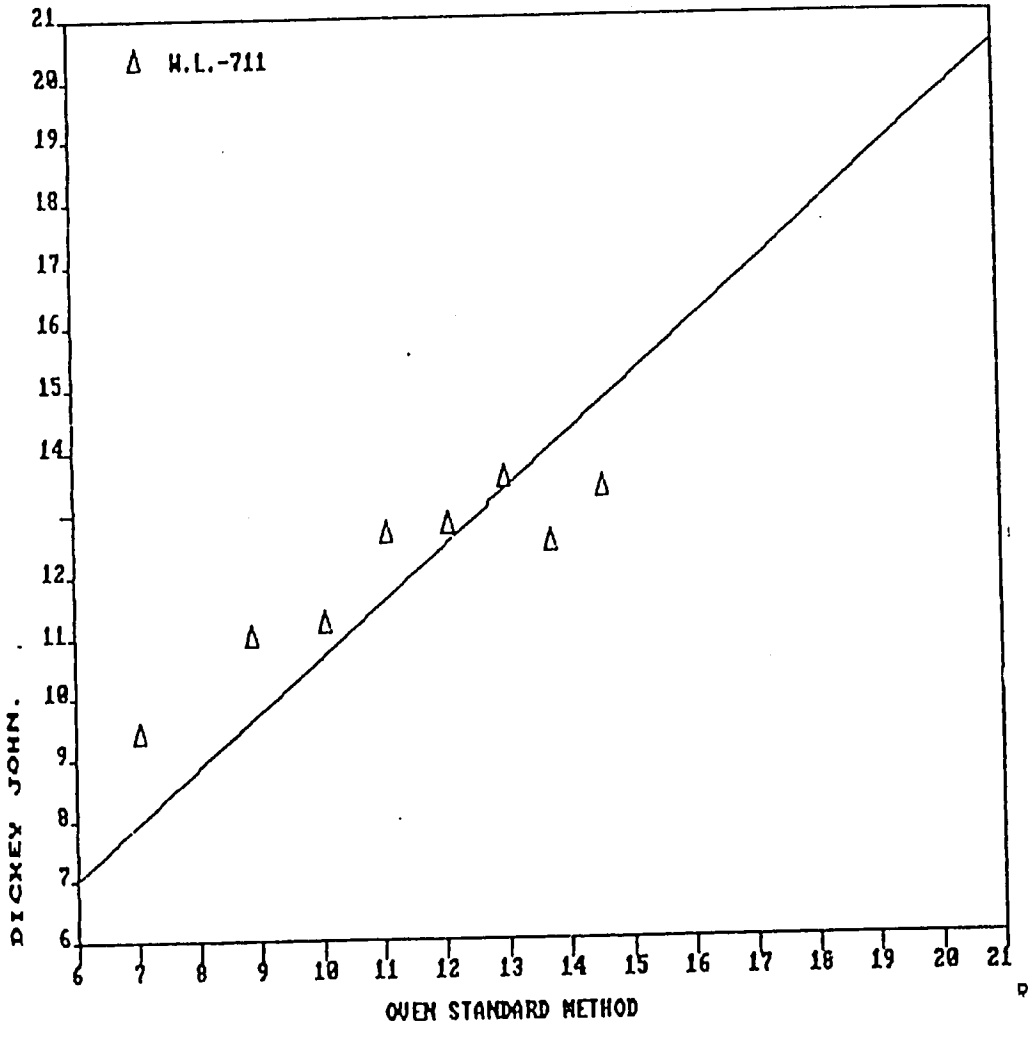
Fig. 4e



THE REGRESSION POLYNOMIAL OF LINE 1 -

(5.288E+00) + (5.435E-01)*X
THE VARIANCE - 3.052E-02

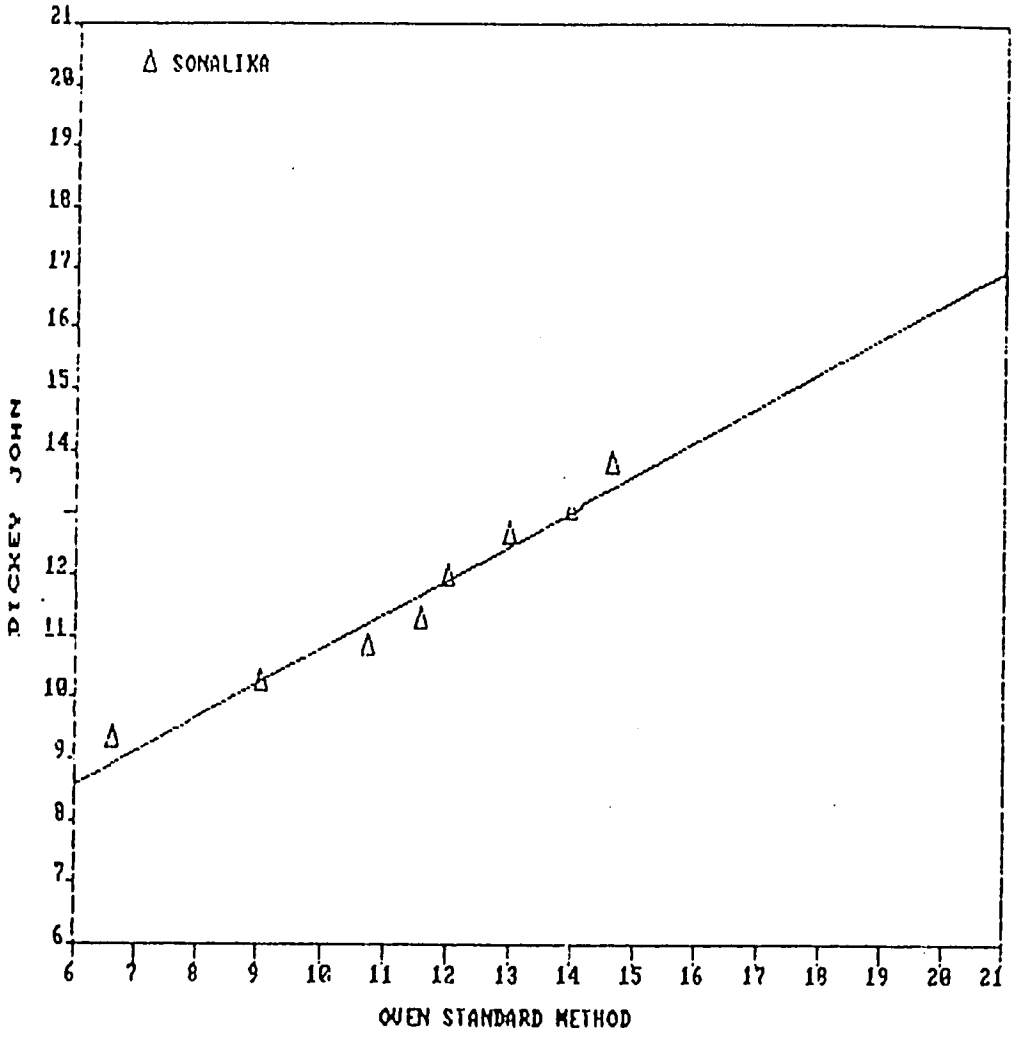
Fig. 4f



THE REGRESSION POLYNOMIAL OF LINE 1 -

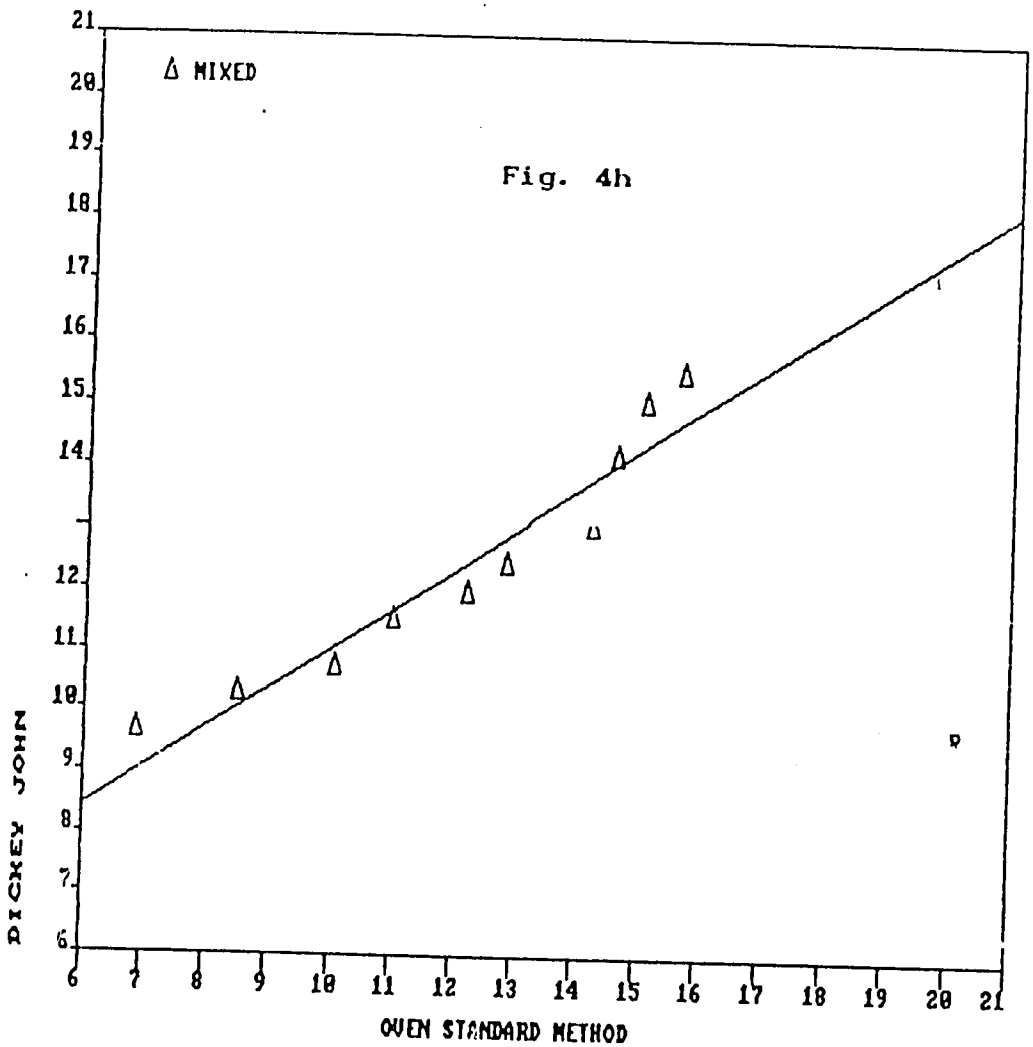
(1.596E+00) + (9.017E-01)*X
THE VARIANCE - 1.334E+00

Fig. 4g



THE REGRESSION POLYNOMIAL OF LINE 1 -

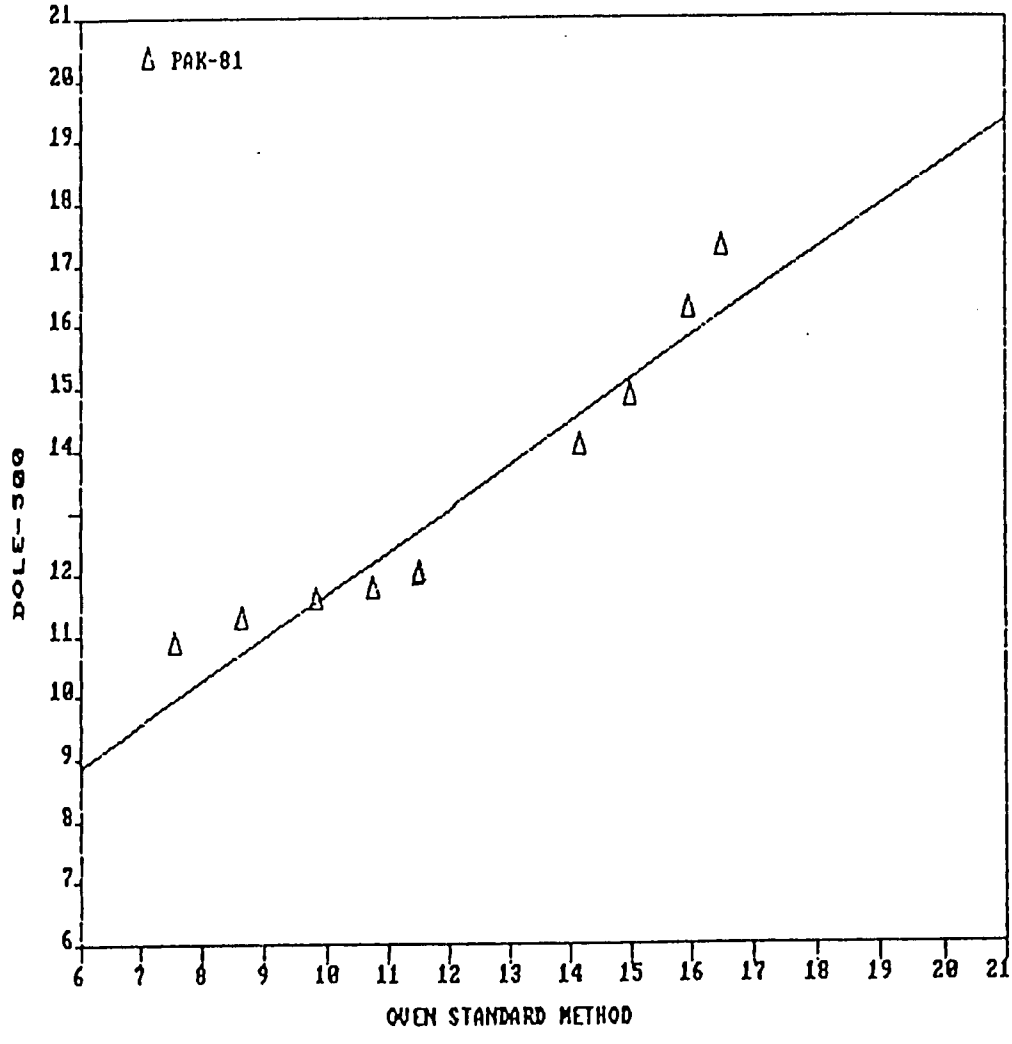
(5.192E+00) + (5.592E-01)*X
THE VARIANCE - 8.608E-02



THE REGRESSION POLYNOMIAL OF LINE 1 -

(4.497E+00) + (6.526E-01)*X
THE VARIANCE - 2.746E-01

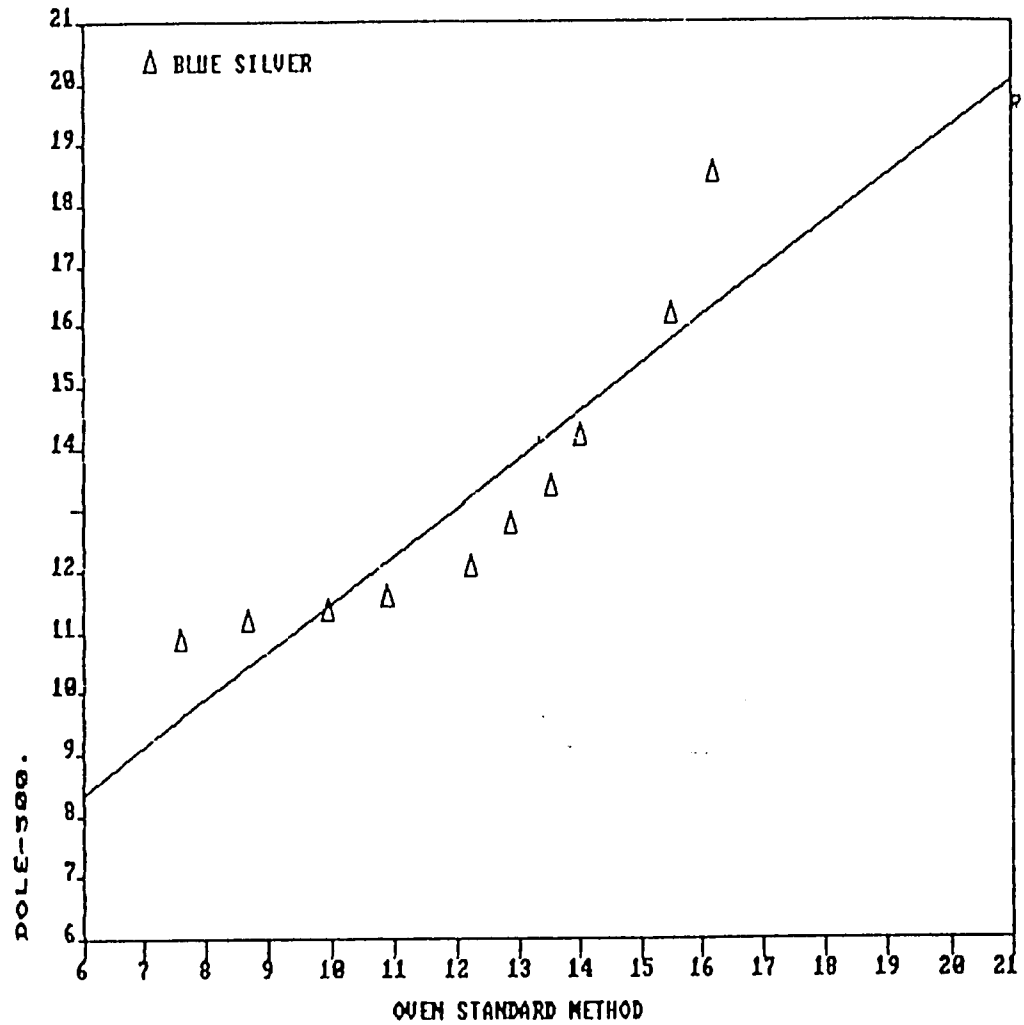
Fig. 5a



THE REGRESSION POLYNOMIAL OF LINE

(4.661E+00) + (6.977E-01)*X
THE VARIANCE - 3.950E-01

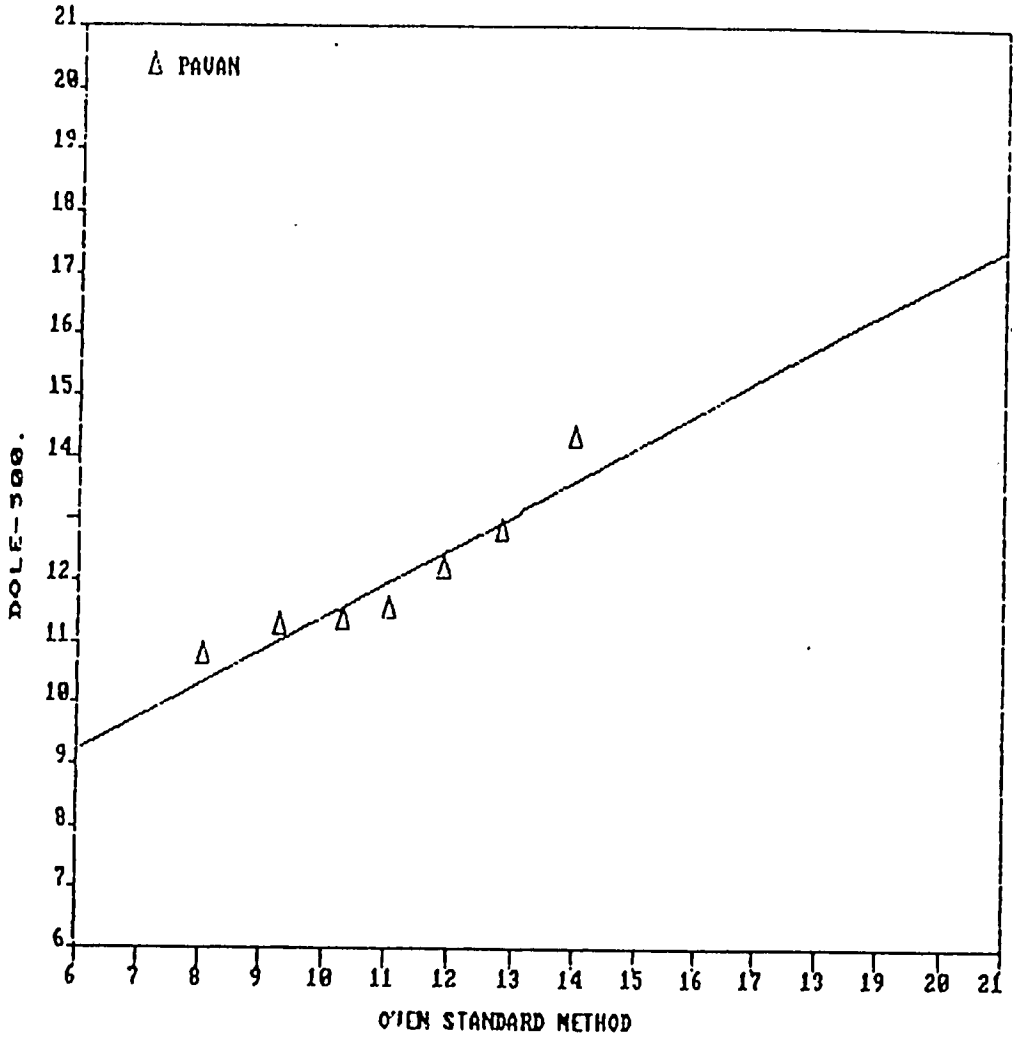
Fig. 5b



THE REGRESSION POLYNOMIAL OF LINE 1 -

(3.648E+00) + (7.806E-01)*X
THE VARIANCE - 1.071E+00

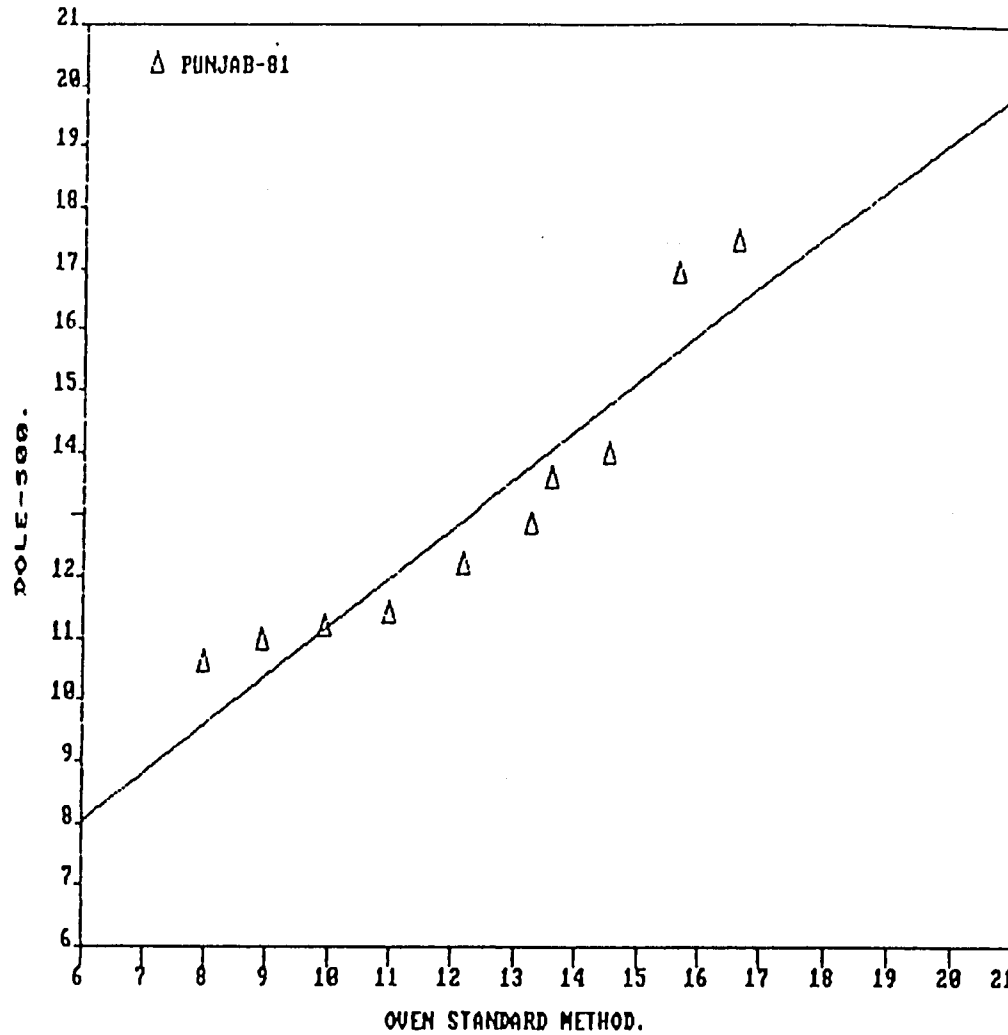
Fig. 5c



THE REGRESSION POLYNOMIAL OF LINE 1 -

(5.908E+00) + (5.491E-01)*X
THE VARIANCE - 1.510E-01

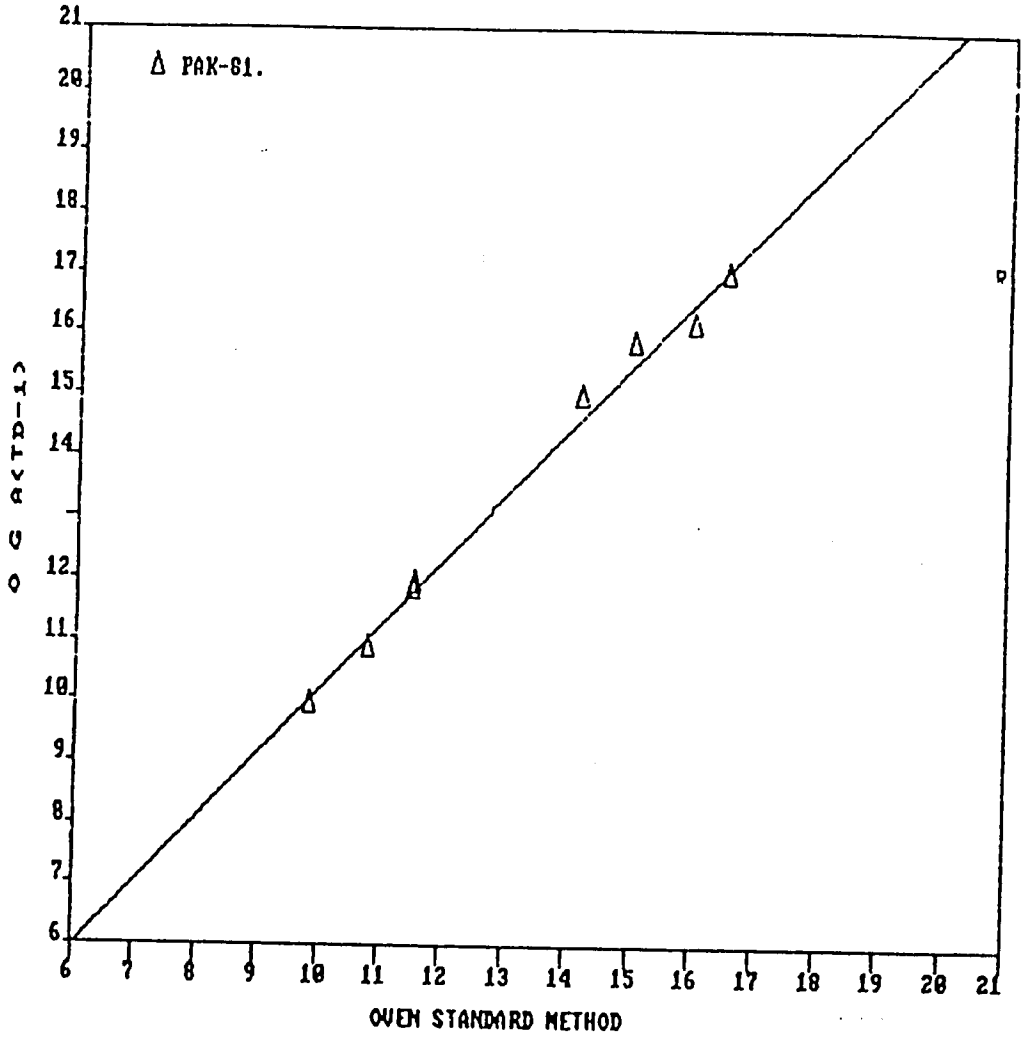
Fig. 5d



THE REGRESSION POLYNOMIAL OF LINE 1

(3.327E+00) + (7.868E-01)*X
THE VARIANCE - 6.554E-01

Fig. 6a

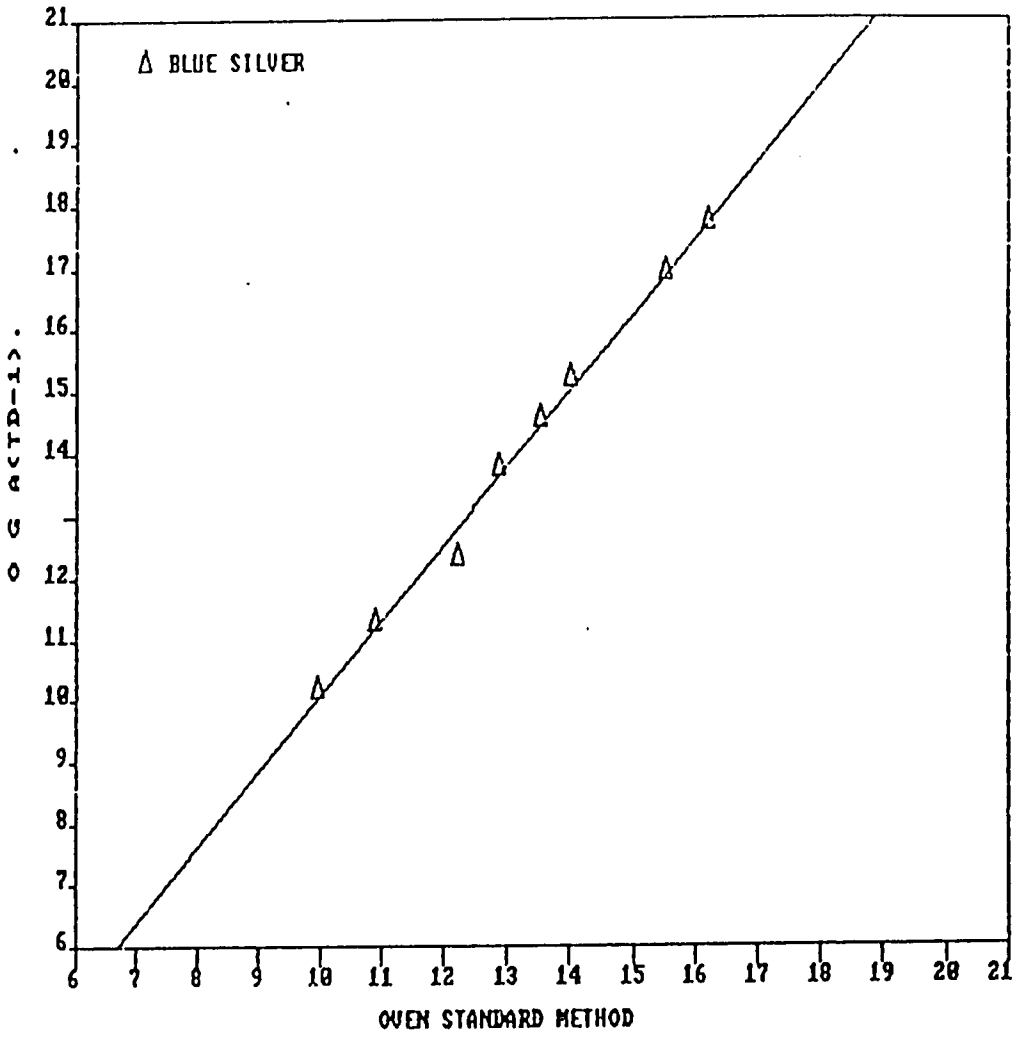


THE REGRESSION POLYNOMIAL OF LINE 1

(-4.057E-01) + (1.059E+00)*X
THE VARIANCE - 5.217E-02

63

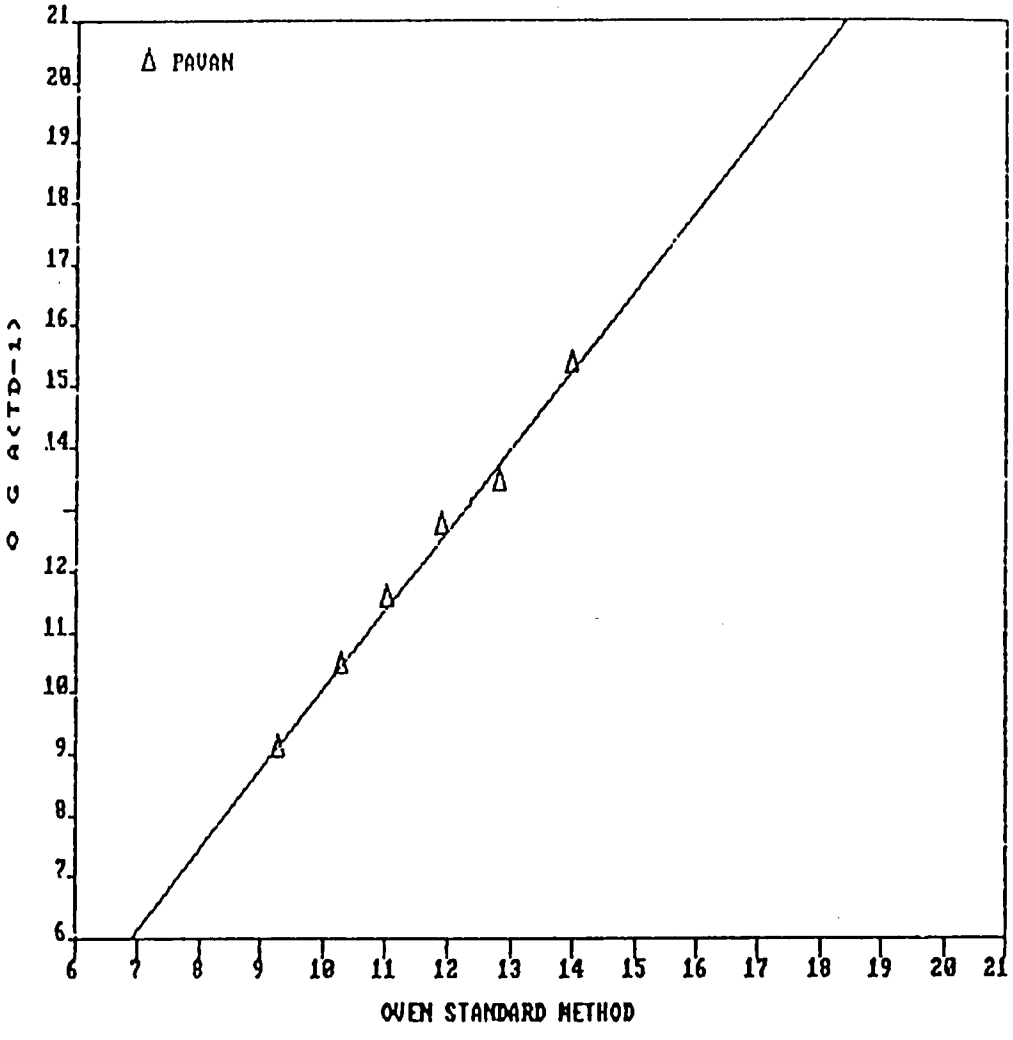
Fig. 6b



THE REGRESSION POLYNOMIAL OF LINE 1 -

(-2.221E+00) + (1.230E+00)*X
THE VARIANCE - 4.048E-02

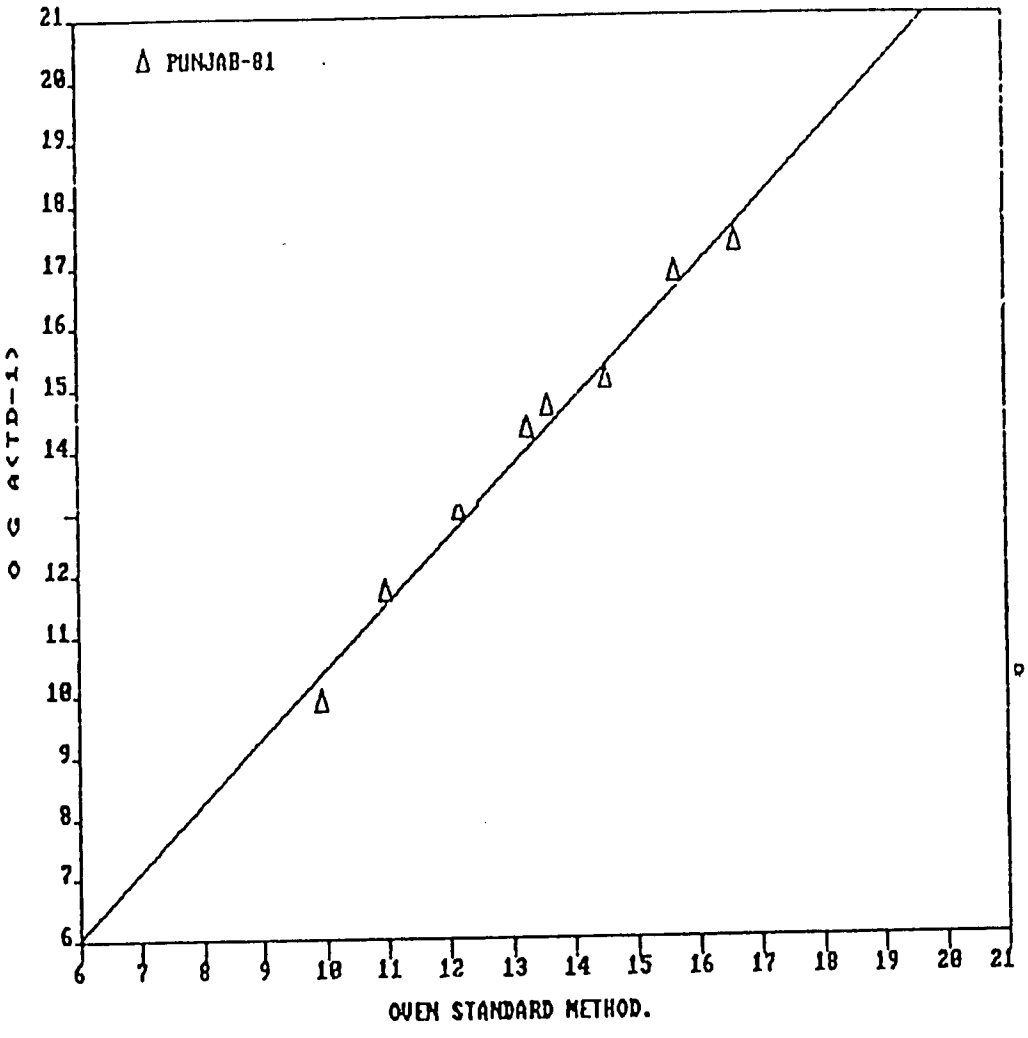
Fig. 6c



THE REGRESSION POLYNOMIAL OF LINE 1 -

(-2.955E+00) + (1.301E+00)*X
THE VARIANCE - 2.931E-02

Fig. 6d

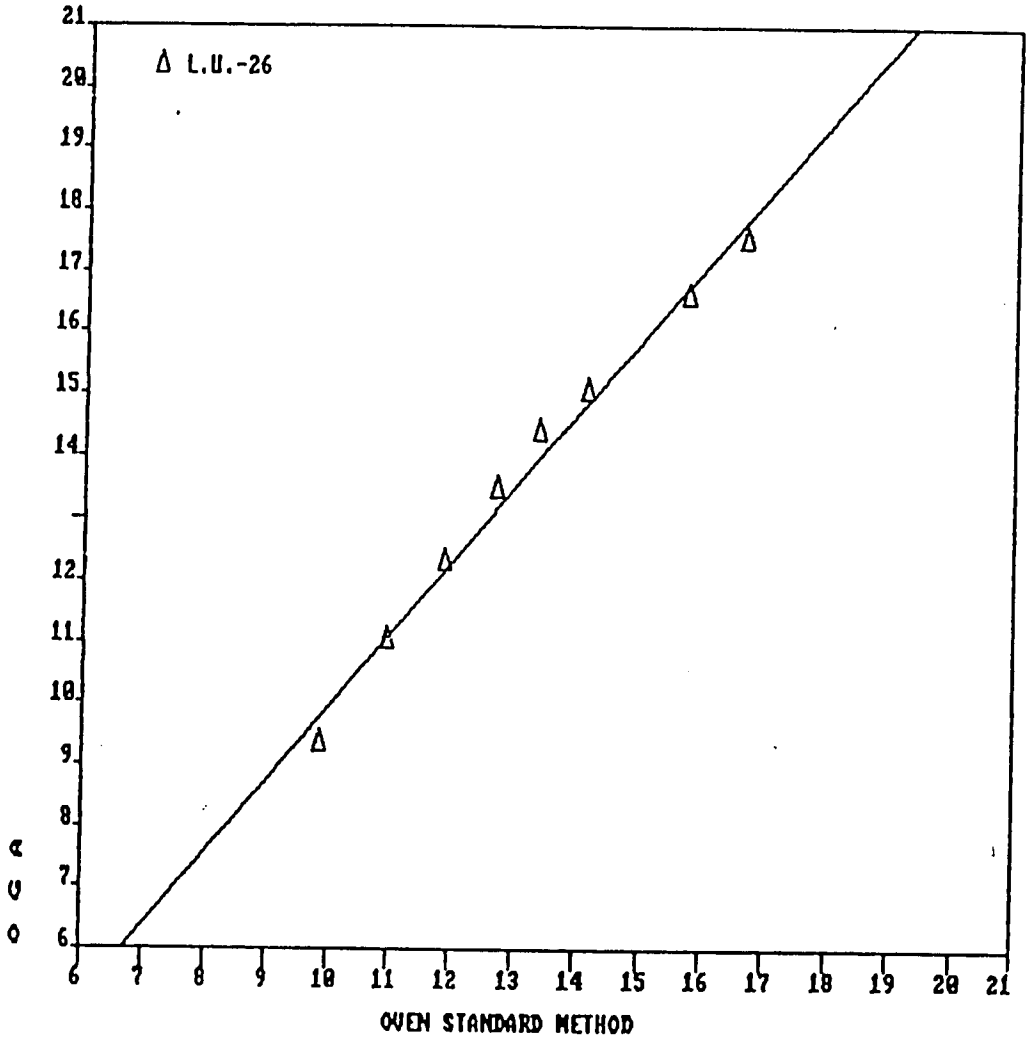


THE REGRESSION POLYNOMIAL OF LINE 1 -

(-4.624E-01) + (1.088E+00)*X
THE VARIANCE - 9.357E-02

66

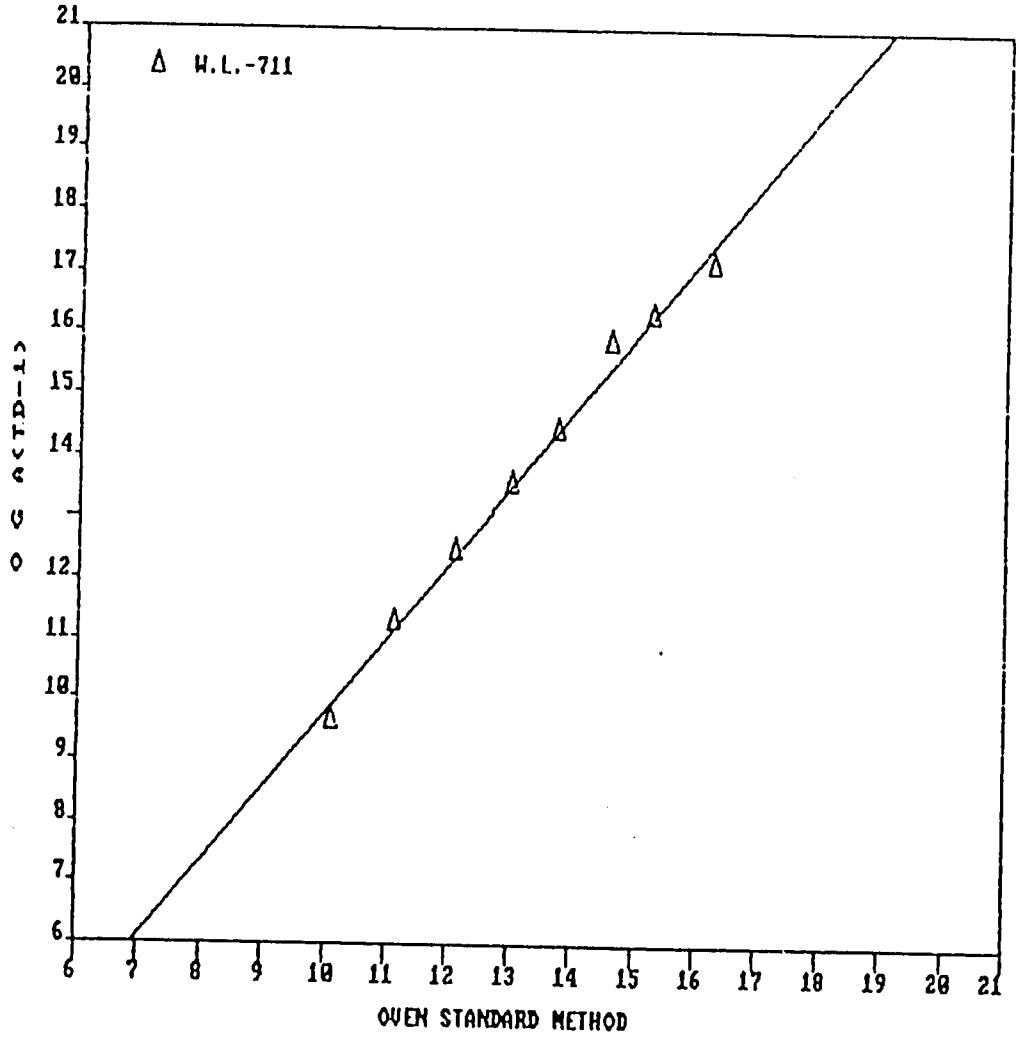
Fig. 6e



THE REGRESSION POLYNOMIAL OF LINE

(-1.953E+00) + (1.187E+00)*X
THE VARIANCE - 8.340E-02

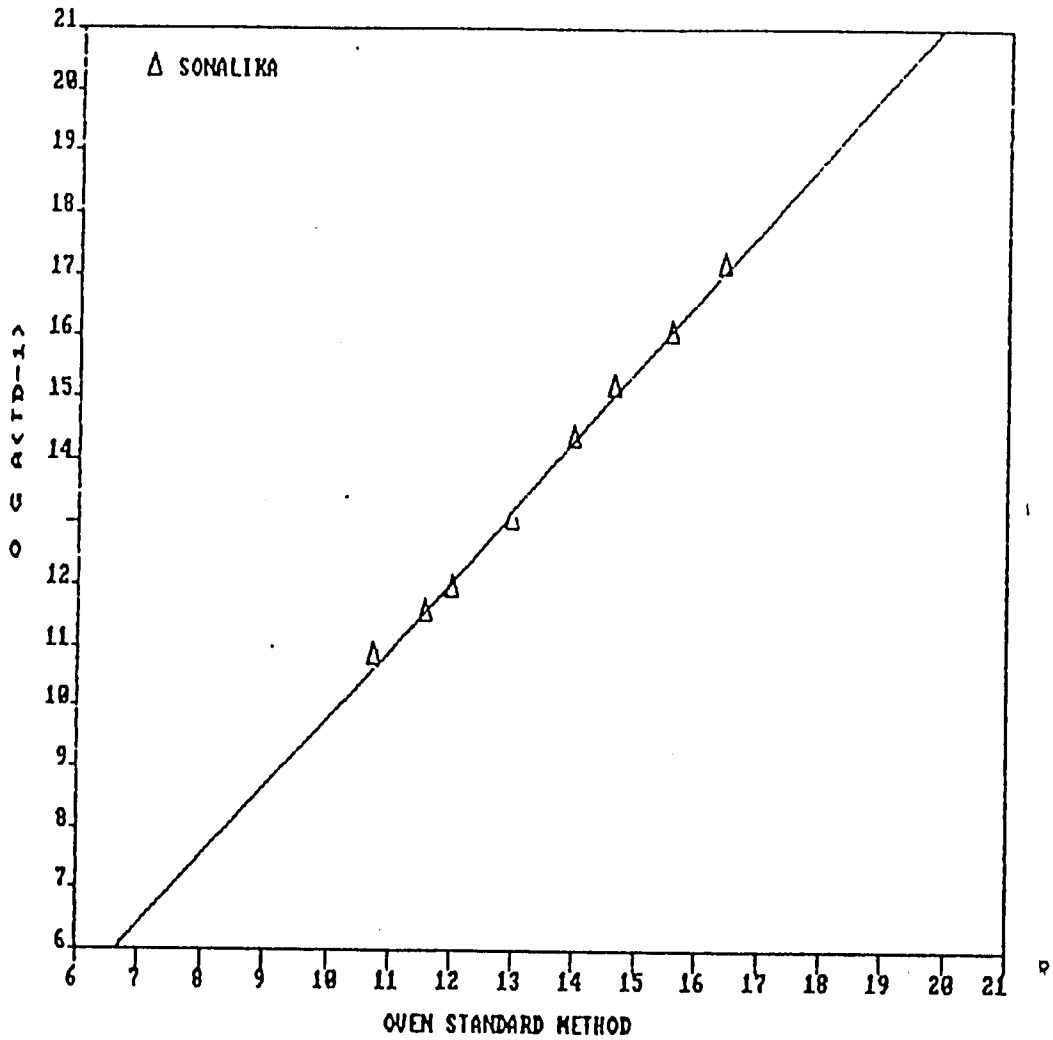
Fig. 6f



THE REGRESSION POLYNOMIAL OF LINE 1 .

(-2.522E+00) + (1.231E+00)*X
THE VARIANCE - 5.091E-02

Fig. 6g

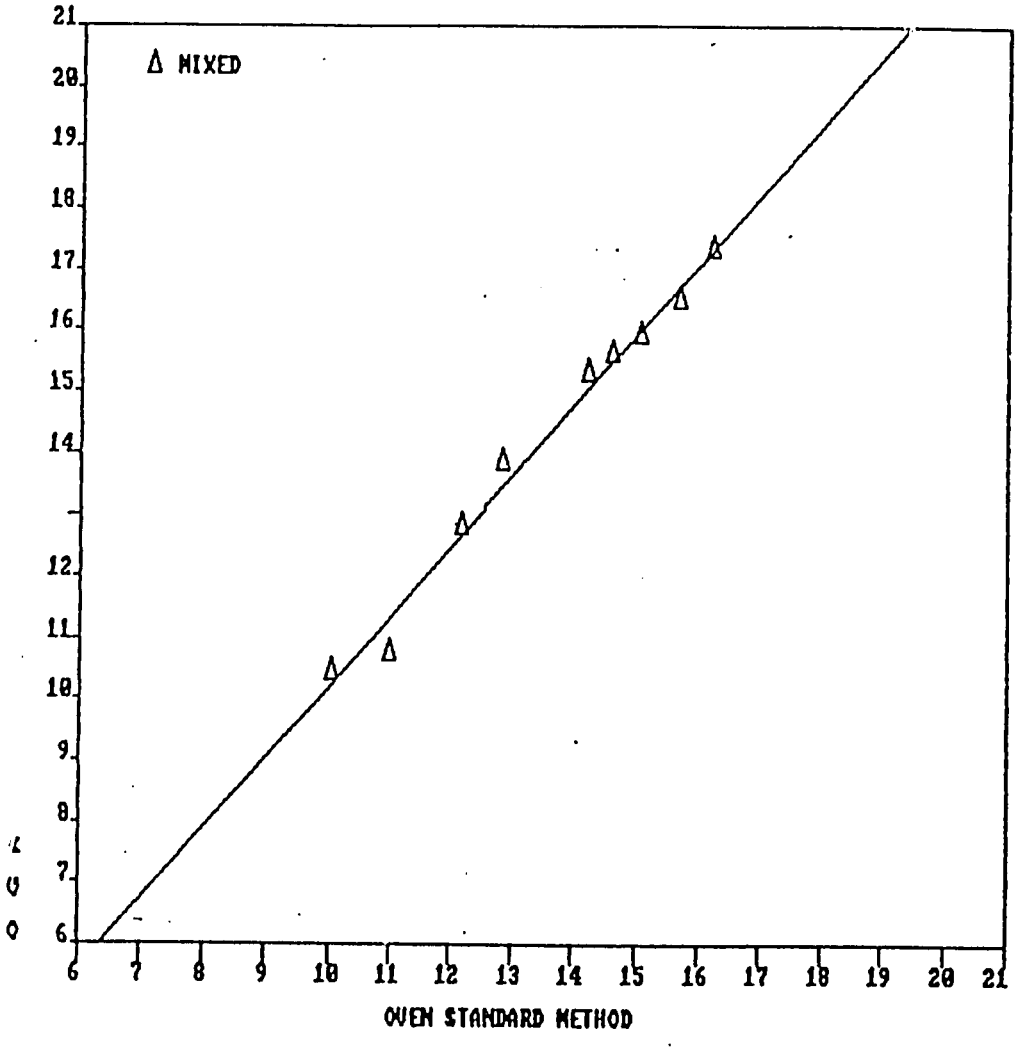


THE REGRESSION POLYNOMIAL OF LINE 1 -

(-1.479E+00) + (1.129E+00)*X
THE VARIANCE - 1.240E-02

69

Fig. 6h



THE REGRESSION POLYNOMIAL OF LINE

(-1.287E+00) + (1.148E+00)*X
THE VARIANCE - 6.939E-02