

A Study of the Measurements of the Air Permeance Bendtsen and Air Permeance Gurley of a 100gsm A4 Photocopy Paper

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Abstract

Comparison of means of two methods of measuring air permeance were conducted using one-way ANOVA. The p-values of ANOVA were found to be $p < 0.000 < 0.05$, and also $p = 0.002 < 0.05$, when using the same units of expression of both permeances, which showed statistically significant differences between the values of the two methods of air permeance Bendtsen and Gurley. In the descriptives table the skewness value of the group of data for air permeance Bendtsen was positive which indicated a tail to the right of the distribution of data, and the kurtosis values for both groups were found below 1 which indicated flat distributions. In the normal Q-Q plots the values of the air permeances Bendtsen and Gurley were found approximately normally distributed since the points of data were close to the line. The detrended normal Q-Q plots gave us the same information. Both air permeance values, Bendtsen and Gurley, were evaluated in $\frac{\mu\text{m}}{\text{Pa}\cdot\text{s}}$ and the sample data followed the normal distribution since sig. (Kolmogorov-Smirnov) = 0.2 and sig. (Shapiro-Wilk) = 0.805. Boxplots were obtained, and equality of variances, with the Levene criterion, i.e. sig. = 0.738 > 0.05, was obtained only when the air permeances were both expressed in units $\frac{\mu\text{m}}{\text{Pa}\cdot\text{s}}$.

Keywords: Air permeance bendtsen; Air permeance gurley; Compare means; One-way ANOVA; Descriptives table; Boxplot; Q-Q plots

Introduction

A paper property which is closely related to its structure is the ability of the paper to allow air to pass through, meaning air permeance [1]. The air permeance is closely related to the pore structure of the paper. It is found that with increasing beating, during making of the paper, the air permeance decreases [1]. The density of paper pulp is correlated to the vacuum level properties when forming sheets. Increased density causes lower permeance [2]. During air permeance measurements air is allowed to penetrate through a paper sample with given dimensions, under standardized pressure, temperature and humidity and the amount of air which passes through the paper per time unit is recorded. The air permeance is calculated according to the equation $P_a = \frac{Q}{A \cdot \Delta p}$ (1) in $\left(\frac{\text{m}}{\text{s}\cdot\text{Pa}}\right)$, where A is the area in m^2 , Δp is the pressure difference across the paper in Pa, and Q is the air flow through the paper in m^3/s . The air permeance according to Gurley is the most common method and in the Gurley-apparatus the pressure difference is 1.21Kpa, while in the Bendtsen apparatus the pressure difference is 1.47KPa. In the Gurley apparatus the air permeance can be evaluated as $P_a = \frac{128}{t}$ (2) in $\left(\frac{\mu\text{m}}{\text{s}\cdot\text{Pa}}\right)$, where t is the time in seconds required for 100ml of air to pass through the paper test piece [3,4]. Besides the Gurley apparatus there are also the Bendtsen instrument and the Bekk instrument for the measuring of air permeance. We can calculate the air permeance Bendtsen

P_a in $\left(\frac{\mu m}{s.Pa}\right)$ from the equation $P_a = 0.0113xq$ (3), where q is the mean air flow rate in ml/min, passing through the test area of 1000mm² at a related pressure of 1.47KPa in the measuring head [4,5].

Materials and Methods

Instruments and materials

The Roughness and the Air Permeance Tester Bendtsen Method, Model No. K513, Messmer Buchel Holland, S. Number:8008-01, 220V, 50Hz, with air permeance test head 10cm², annulus pressure on the specimen 100KPa, test pressure 1.47KPa, accuracy 0.02KPa at 1.47KPa, test area 10cm², was used for measuring the air permeance Bendtsen value [5] of the A4 100gsm Multipaper Fabriano copy paper sample. The tester measured the paper test pieces of dimensions 100mmx100mm. Ten paper test pieces were measured, previously cut in a guillotine IDEAL 1043 GS made in Germany. The Gurley air permeance tester was a Gurley Precision Instruments model 4110, Serial Number:9900114, used for measuring the air permeance Gurley value [3] of the A4 100gsm Multipaper Fabriano copy paper sample. Ten paper test pieces were also measured, previously cut in a guillotine IDEAL 1043 GS

made in Germany. The paper test pieces were conditioned for 16 hours at 23±1 °C temperature and 50% ± 2% relative humidity in accordance with the ISO 187 standard [6] and were tested in the same conditioning atmosphere, in a conditioning chamber capable of providing and maintaining standard conditions of temperature and humidity. The IBM SPSS data analysis software was used throughout all this study.

Results and Discussion

In this work the air permeance results were obtained from measurements of Bendtsen air permeance and also from measurements of Gurley air resistance since that method had a lower detection limit ($0.1 \frac{\mu m}{Pa.s}$) than the Bendtsen method ($0.35 \frac{\mu m}{Pa.s}$) [7].

The data of the first two columns of Table 1 were plotted and a linear relation of the two air permeances was revealed. Before performing the ANOVA test, we checked to ensure that our data in Table 1 was normally distributed. The two tests of normality, namely the Kolmogorov-Smirnov test, and the Shapiro-Wilk test were the most widely used methods to test the normality of our data (Figure 1).

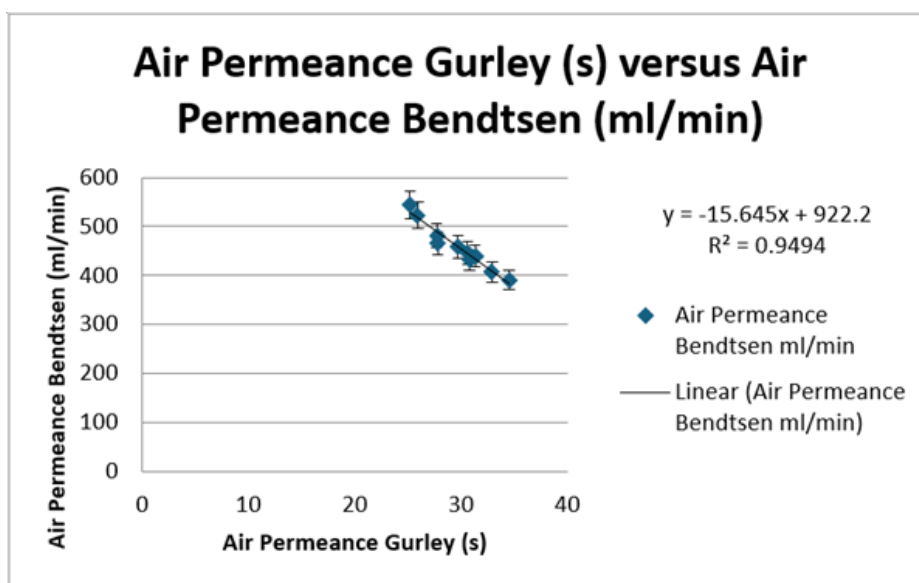


Figure 1: Graph of air permeance Gurley in (s) versus air permeance Bendtsen in (ml/min) from the data in Table 1, showed their linear relation.

Table 1: Data of the ANOVA, showing the air permeance Bendtsen in ml/min and air permeance Gurley in s/100ml air, of the 100gsm A4 copy paper sample Fabriano. This table was used for presenting the dependent parameter in performing one-way ANOVA, and Factor K.

Copy paper values Air Permeance Bendtsen/Air Permeance Gurley	Air Permeance Bendtsen (ml/min)-Air permeance Gurley (s)-Dependent List-Air Permeance Gurley	Factor K
Air Permeance Bendtsen value	431ml/min	1
Air Permeance Bendtsen value	523ml/min	1
Air Permeance Bendtsen value	390ml/min	1
Air Permeance Bendtsen value	465ml/min	1
Air Permeance Bendtsen value	459ml/min	1
Air Permeance Bendtsen value	439ml/min	1
Air Permeance Bendtsen value	544ml/min	1

Air Permeance Bendtsen value	407ml/min	1
Air Permeance Bendtsen value	481ml/min	1
Air Permeance Bendtsen value	446ml/min	1
Air Permeance Gurley value	30.8s	2
Air Permeance Gurley value	25.9s	2
Air Permeance Gurley value	34.5s	2
Air Permeance Gurley value	27.8s	2
Air Permeance Gurley value	29.7s	2
Air Permeance Gurley value	31.3s	2
Air Permeance Gurley value	25.2s	2
Air Permeance Gurley value	32.9s	2
Air Permeance Gurley value	27.7s	2
Air Permeance Gurley value	30.6s	2

In Table 2 the quantity Sig.(significance) was the probability of making a mistake if we have accepted that the sample data did not follow the normal distribution. In general, when the sig. was greater than 0.05, we accepted that the distribution was normal.

So, in the sample data we have examined the values followed the normal distribution given that sig. (Kolmogorov-Smirnov) =0.2 and sig. (Shapiro-Wilk) =0.805 applied [8].

Table 2: Tests of Normality of data.

Tests of Normality							
K		Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Air Permeance Gurley	1	0,146	10	,200*	0,962	10	0,805
	2	0,131	10	,200*	0,970	10	0,888
*. This is a lower bound of the true significance.							
a. Lilliefors Significance Correction							

In Table 3 we observed that the statistical test of dispersions with the Levene criterion gave the value $p=0.002<0.05$ which showed that H_0 , the null hypothesis was rejected, and that there

was no equality of variances for the two groups of data in Table 1, namely air permeance Bendtsen and air permeance Gurley [9].

Table 3: Test of Homogeneity of the variances

Test of Homogeneity of Variances					
		Levene Statistic	df1	df2	Sig.
Air Permeance Gurley	Based on Mean	12,970	1	18	,002
	Based on Median	12,401	1	18	,002
	Based on Median and with adjusted df	12,401	1	9,058	,006
	Based on trimmed mean	12,952	1	18	,002

From the Table 4 descriptives it was shown that the median for group 1, air permeance Bendtsen was $Q_2=452.5\text{ml}/\text{min}$, the second quartile, and the $\text{IQR}=66.5\text{ml}/\text{min}$ and also the median for group 2, air permeance Gurley was $Q_2=30.150\text{s}$, and the IQR (Interquartile Range) was 4.4s. Also, the skewness value of 0.527 for group 1 was positive indicating a tail to the right of our distribution of data and the kurtosis value below 1, i.e. -0.163, indicated a flat distribution. The skewness value of group 2 was also positive, i.e. 0.016,

indicating a tail to the right, and the kurtosis value was -0.784, below 1 indicated also a flat distribution. Comparing though the mean value with the median value for group 1 data, i.e. $458.5\text{ml}/\text{min} > 452.5\text{ml}/\text{min}$ we concluded that the distribution was skewed to the right, while the mean value was smaller than the median, i.e. $29.640\text{s} < 30.150\text{s}$ for group 2 data, and the distribution was skewed to the left.

Table 4: Results of Descriptive Statistics [10].

Descriptives					
		K	Statistic	Std. Error	
Air Permeance Gurley	1	Mean	458,500	15,1498	
		95% Confidence Interval for Mean	Lower Bound	424,229	
			Upper Bound	492,771	
		5% Trimmed Mean	457,556		
		Median	452,500		
		Variance	2295,167		
		Std. Deviation	47,9079		
		Minimum	390,0		
		Maximum	544,0		
		Range	154,0		
		Interquartile Range	66,5		
		Skewness	,527	,687	
		Kurtosis	-,163	1,334	
	2	Mean	29,640	,9435	
		95% Confidence Interval for Mean	Lower Bound	27,506	
			Upper Bound	31,774	
		5% Trimmed Mean	29,617		
		Median	30,150		
		Variance	8,903		
		Std. Deviation	2,9837		
		Minimum	25,2		
		Maximum	34,5		
		Range	9,3		
		Interquartile Range	4,4		
		Skewness	,016	,687	
		Kurtosis	-,784	1,334	

In Table 5 the p-value of ANOVA $p=0.000 < 0.05$ applied. The value was close to 0, which indicated that the observed difference was unlikely to have been to chance. That meant at a significant level of $\alpha=0.05$ there were statistically significant differences between the air permeances values of the two methods Bendtsen and Gurley of Table 1 [11]. Also, $F(0.05, 1,18)=798.244 > 4.4139$. Here the F statistic [12] was larger than the critical F-value and the observed differences among the sample means could not reasonably be due to random chance alone. There was insufficient evidence to suggest that the two populations came from the same population of scores. We accepted that the two groups' variances were significantly different [12]. The result was statistically significant and we rejected the null hypothesis that the means of the two groups of data, air permeance Bendtsen and air permeance Gurley were equal.

Table 5: ANOVA table.

ANOVA					
Air Permeance Gurley					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	919604,498	1	919604,498	798,244	,000
Within Groups	20736,624	18	1152,035		
Total	940341,122	19			

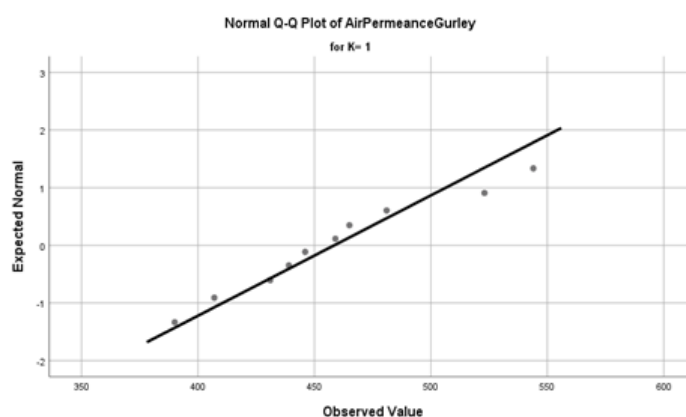
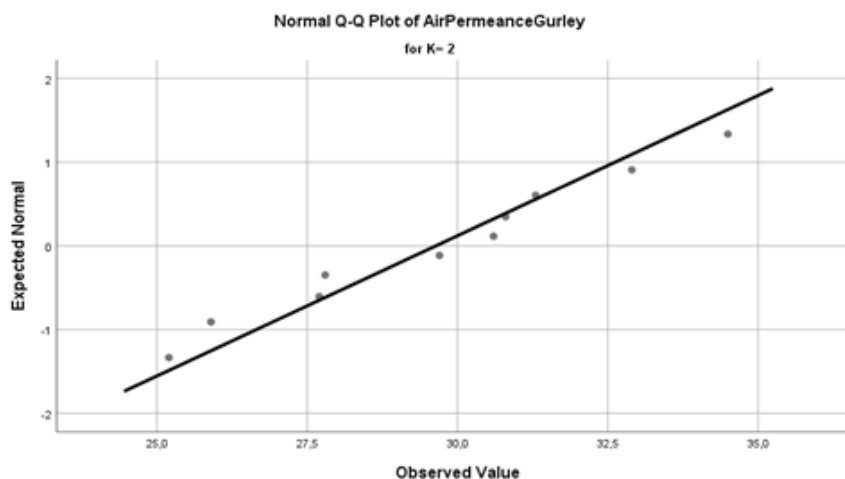
In Table 6 the column valid referred to the non-missing cases of the data in Table 1, which were 10 for both groups of data. In the column missing there was the number of missing cases which was 0. The column total contained the total number of cases in the data set.

Table 6: The Case processing summary.

Case Processing Summary							
	K	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
Air Permeance	1	10	100,0%	0	0,0%	10	100,0%
Gurley	2	10	100,0%	0	0,0%	10	100,0%

The normal Q-Q (Quantile-Quantile) plots in Figures 2 and 3 compared the observed quantiles of the data of air permeance

Bendtsen and air permeance Gurley respectively, depicted as dots, with the quantiles that we would have expected to see if our data of Table 1 were normally distributed (depicted as a solid line) [13]. The Q-Q plots (quantile-quantile) plots were probability plots. That kind of probability plot plotted the quantiles of our variable's distribution against the quantiles of a test distribution. Our data for air permeance Bendtsen (Figure 2) K=1, and for air permeance Gurley (Figure 3) K=2, were approximately normally distributed, since the points were close to the line. But still when we looked at a Q-Q plot we looked also for points that strayed far from the lines of expected values. Then the Detrended Normal Q-Q Plots were produced.

**Figure 2:** Q-Q plot for the check of normal distribution for the values of Air Permeance Bendtsen, K=1.**Figure 3:** Q-Q plot for the check of normal distribution for the values of Air Permeance Gurley, K=2. Then the Detrended Normal Q-Q Plots were produced.

The detrended normal Q-Q plots in Figures 4 and 5 showed the same information as the normal Q-Q plots but in a different manner [14]. In the detrended plot the horizontal line at the origin represented the quantiles that we would have expected to see if our data were normal. The dots in Figures 4 and 5 represented the magnitude and direction of deviation in the observed quantiles.

Each dot was calculated by subtracting the expected quantiles from the observed quantiles. That assumption implied that the dots which were below the trend line on the normal Q-Q plots, appeared above the trend line on the detrended normal Q-Q plot, since observed-expected > 0.

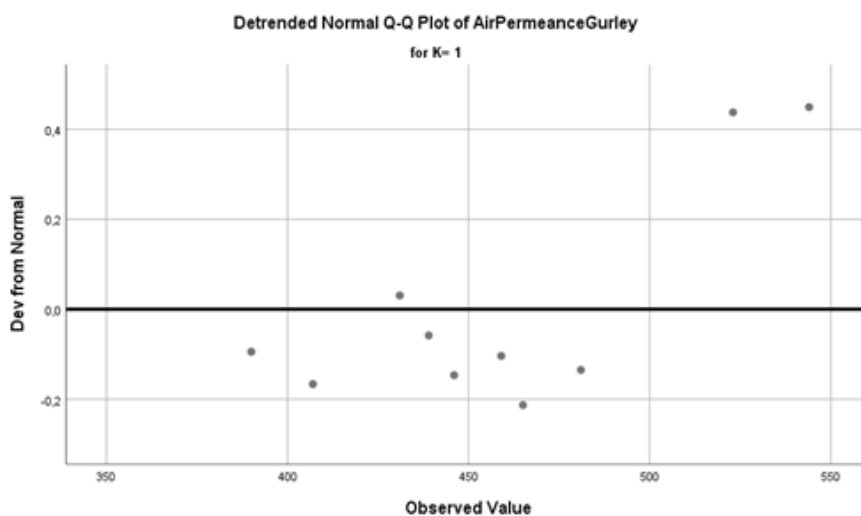


Figure 4: Detrended normal Q-Q plot for the check of normal distribution for the values of air permeance Bendtsen, $K=1$.

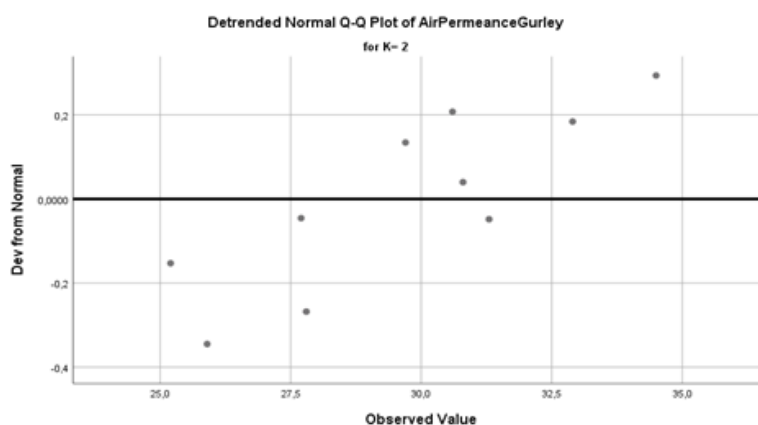


Figure 5: Detrended normal Q-Q plot for the check of normal distribution for the values of air permeance Gurley, $K=2$.

In addition to the hypothesis tests and the quantile-quantile plots of the data of Table 1 we looked at a boxplot of our two groups of data. The boxplots in Figure 6 gave us a better look at the outliers and the location of our quantiles, of our two groups of data [15]. The boxplots of the two samples of our observations 1 and 2, showed the quartiles Q_1 , Q_2 , and Q_3 with the help of a vertically oriented rectangle. It also showed their extreme values as in group 1 of data of Figure 6. The bottom side of the rectangle of our first group of data (i.e. air permeance Bendtsen), was at the height of the first quartile Q_1 and the top side was at the height of the third

quartile Q_3 , and the intermediate parallel corresponded to the median of the sample group Q_2 . Because the median $Q_2=452.5\text{ml}/\text{min}$ divided approximately the rectangle of group 1 into two equal parts we assumed that its distribution was symmetrical. The box plot of group 1 also included two lines outside the rectangle. The first extended from Q_1 to $Q_1-1.5\text{IQR}$, where $\text{IQR}=Q_3-Q_1=66.5\text{ml}/\text{min}$ which was the interquartile range. The observations for group 1 of our data, in Figure 6, that were between 1.5IQR and 3IQR from the upper and the lower side of the boxplot were considered as external outliers.

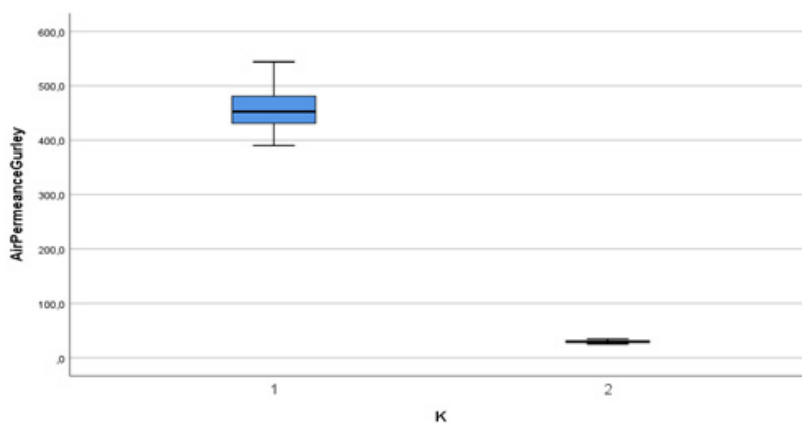


Figure 6: Boxplot of our two groups of data of Table 1.

The Bendtsen air permeance measurements, and the Gurley air permeance measurements, in Table 1, were evaluated also in $\left(\frac{\mu m}{Pa.s}\right)$ units, [16] according to equations (2) and (3) and were presented

in Table 7. In Table 8 there was the case processing summary with the valid, i.e. non-missing cases, the missing cases which were 0 and the total cases which were 10.

Table 7: Data of the ANOVA, showing the air permeance Bendtsen in $\mu m/Pa.s$ and air permeance Gurley in $\mu m/Pa.s$, of the 100gsm A4 copy paper sample Fabriano. This table was used for presenting the dependent parameter in performing one-way ANOVA, and the Factor M.

Copy paper values Air Permeance Bendtsen/Air Permeance Gurley	Air Permeance Bendtsen ($\mu m/Pa.s$)-Air permeance Gurley ($\mu m/Pa.s$)-Dependent List-Air Permeance bendtsengurley	Factor M
Air Permeance Bendtsen value	4.8703	1
Air Permeance Bendtsen value	5.9099	1
Air Permeance Bendtsen value	4.4070	1
Air Permeance Bendtsen value	5.2545	1
Air Permeance Bendtsen value	5.1867	1
Air Permeance Bendtsen value	4.9607	1
Air Permeance Bendtsen value	6.1472	1
Air Permeance Bendtsen value	4.5991	1
Air Permeance Bendtsen value	5.4353	1
Air Permeance Bendtsen value	5.0398	1
Air Permeance Gurley value	4.1558	2
Air Permeance Gurley value	4.9420	2
Air Permeance Gurley value	3.7101	2
Air Permeance Gurley value	4.6043	2
Air Permeance Gurley value	4.3098	2
Air Permeance Gurley value	4.0895	2
Air Permeance Gurley value	5.0794	2
Air Permeance Gurley value	3.8906	2
Air Permeance Gurley value	4.6209	2
Air Permeance Gurley value	4.1830	2

Table 8: The case processing summary.

Case Processing Summary							
	Valid			Cases Missing		Total	
	M	N	Percent	N	Percent	N	Percent
Air permeance bendtsen gurley	1	10	100.00%	0	0.00%	10	100.00%
	2	10	100.00%	0	0.00%	10	100.00%

Table 9 the descriptives table showed the summary statistics for each of the two groups of data in Table 7, and in this table all statistics were in the same physical units as the variables in Table 7 that were in $\frac{\mu m}{Pa.s}$. The median for group 1 of the data in Table 7 was $Q_2=5.113250\mu m/Pa.s$ for air permeance Bendtsen and the IQR was $0.7515\mu m/Pa.s$. The skewness and kurtosis values were

the same as in Table 4. The median value for group 2 of the data in Table 7 was $Q_2=4.246350\mu m/Pa.s$ for the values of air permeance Gurley and the IQR was $0.6615\mu m/Pa.s$. The skewness value for group 2 was positive, i.e. 0.313, indicating a tail to the right of the data distribution and the kurtosis value was -0.823 indicating a flat distribution.

Table 9: The Descriptives table.

Descriptives					
M		Statistic		Std. Error	
Air permeance bendtsen gurley	1	Mean		5,181050	,1711928
		95% Confidence Interval for Mean	Lower Bound	4,793785	
			Upper Bound	5,568315	
		5% Trimmed Mean		5,170378	
		Median		5,113250	
		Variance		,293	
		Std. Deviation		,5413592	
		Minimum		4,4070	
		Maximum		6,1472	
		Range		1,7402	
		Interquartile Range		,7515	
		Skewness		,527	,687
	Kurtosis		-,163	1,334	
	2	Mean		4,358510	,1404490
		95% Confidence Interval for Mean	Lower Bound	4,040792	
			Upper Bound	4,676228	
		5% Trimmed Mean		4,354489	
		Median		4,246350	
		Variance		,197	
		Std. Deviation		,4441387	
		Minimum		3,7101	
		Maximum		5,0793	
Range			1,3692		
Interquartile Range		,6615			
Skewness		,313	,687		
Kurtosis		-,823	1,334		

In Table 10 the sample data of Table 7 followed the normal distribution given that sig. (Kolmogorov-Smirnov)=0.2, and sig. (Shapiro-Wilk)=0.805.

Table 10: The Tests of Normality.

Tests of Normality							
	M	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Air permeance bendtsen gurley	1	,146	10	,200*	,962	10	,805
	2	,154	10	,200*	,960	10	,786
*. This is a lower bound of the true significance.							
a. Lilliefors Significance Correction							

The boxplots in Figure 7 gave us a new look at the outliers and the location of quantiles of both groups of data 1, and 2 of Table 7. The mean value was $5.181050\mu m/(Pa.s)$ for group 1 of air

permeance Bendtsen, and the mean value was $4.358510\mu m/(Pa.s)$ for group 2 of air permeance Gurley, respectively. The median value Q_2 was $5.113250\mu m/(Pa.s)$ for air permeance Bendtsen, and the

median value Q2 was $4.246350\mu\text{m}/(\text{Pa}\cdot\text{s})$ for air permeance Gurley, which were the thick black horizontal lines respectively, inside the two boxplots. The two medians divided each of the distributions into two halves with equal probabilities. Because the median for

the group 1 of our data divided the rectangle into two equal parts we assumed that its distribution was symmetrical, unlikely with the data of group 2 which indicated a non-symmetrical distribution.

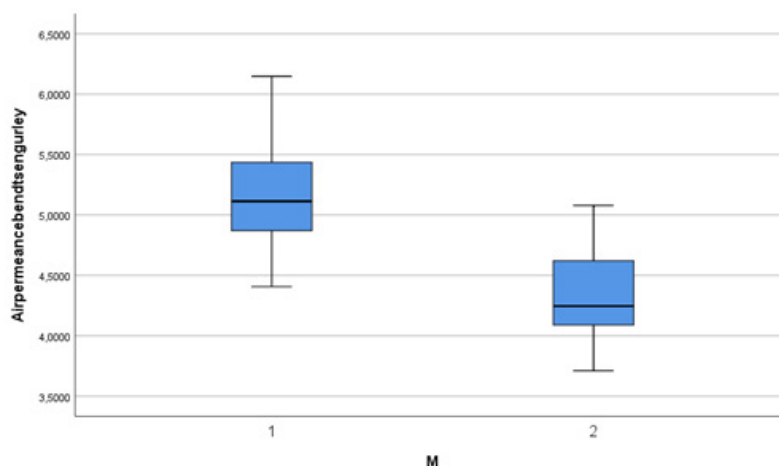


Figure 7: The boxplots for the two groups of data of Table 7.

Table 11 included the sizes of the two groups of data, the mean values, the standard deviations and the 95% confidence intervals for means [17]. The lower bound was the value that was less than or equal to every element of the set of data. Upper bound was a value that was greater than or equal to every element of the set of our two

groups of data. Because those confidence intervals did not contain zero, we concluded that for level of importance $\alpha=0.05$ from these data that there was a difference of the means of our two groups of data [18] and that the mean of group 1 was greater than the mean of group 2.

Table 11: The Descriptives Table.

Descriptives								
Air permeance bendtsen gurley			95% Confidence Interval for Mean					
N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum	
1	10	5,181,050	,5413592	,1711928	4,793785	5,568315	4,4070	6,1472
2	10	4,358510	,4441387	,1404490	4,040792	4,676228	3,7101	5,0793
Total	20	4,769780	,6405516	,1432371	4,469993	5,069567	3,7101	6,1472

In Table 12 we had the results of equality of variances check. We observed that the statistical test of dispersions with the Levene criterion gave the value $p=0.738>0.05$ which showed that the null hypothesis was not rejected, i.e. equality of variances, and so ANOVA

could be applied, in contrast to the results in Table 3. Because the p-value was large in relation to the $\alpha=0.05$ value, that meant that statistically we accepted the null hypothesis [19].

Table 12: Results of equality of variances check.

Test of Homogeneity of Variances					
		Levene Statistic	df1	df2	Sig.
Air permeance bendtsen gurley	Based on Mean	,115	1	18	,738
	Based on Median	,149	1	18	,704
	Based on Median and with adjusted df	,149	1	17,134	,704
	Based on Trimmed mean	,119	1	18	,734

We noticed in Table 13 that for the p-value of ANOVA $p=0.002<0.05$ applied. Thus, at a significance level of $\alpha=0.05$ there were statistically significant differences between the values of the two air permeances [20] of the A4 copy paper sample from Table

13. Also, $F\text{-test}(0.05, 1, 18)=13.798>4.4139$ and we could conclude that there was at least one parameter value that was nonzero and that the two groups variances were significantly different.

Table 13: ANOVA table.

ANOVA					
Air permeance bendtsen gurley					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3,383	1	3,383	13,798	,002
Within Group	4,413	18	,245		
Total	7,796	19			

Conclusion

We attempted to relate the paper property of air permeance according to Bendtsen and according to Gurley. We examined the normality of the values of the two air permeances and we found that they followed the normal distribution given that sig.(Kolmogorov-Smirnov)=0.2 and sig.(Shapiro-Wilk)=0.895. When the two air permeances were expressed in unit's ml/min for air permeance Bendtsen and in s/100ml air for air permeance Gurley we did not observe equality of variances with the Levene Statistic, i.e. $p=0.002<0.05$. For the p -value= $0.000<0.05$ of ANOVA we concluded that there were statistically significant differences between the air permeances of the two methods. From the normal Q-Q plots we obtained that our data for air permeance Bendtsen and Gurley were approximately normally distributed since the points were close to the line.

When the two air permeances were both evaluated in $\frac{\mu m}{Pa.s}$ units we observed that the sample data followed the normal distribution. We obtained equality of variances with the Levene criterion i.e. $p=0.738>0.05$ and the null hypothesis was not rejected. For the p -value of ANOVA $p=0.002<0.05$ and there were also statistically significant differences between the values of the two air permeances of the A4 copy paper sample.

In this work we tried to relate the values of the air permeances according to Bendtsen and according to Gurley but we found that there were statistically significant differences between the two permeances. That conclusion was produced after the one-way ANOVA was applied which was used to check the variability of group means. It was found that the means were not equal and the null hypothesis was rejected. It seemed that the mean value of air permeance Bendtsen did not affect directly the mean value of air permeance Gurley of the copy paper sample tested. It appeared that Bendtsen air permeance was producing different results from measuring Gurley air resistance. The Gurley method may have been only considering penetrating pores with regard to gas transport, but the Bendtsen method may have included also the closed pores and measured the total pore volume of the paper sample.

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