

## LASER SCATTERING SYSTEM FOR INVESTIGATING THE AEROSOL PARTICLE SIZES AND NEBULIZERS EFFICIENCY

BY

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### ABSTRACT

A laser Scattering System has been built for aerosol investigation. The aerosol particle size, at different solution flow rates and at different heights from the aerosol tube rim, has been investigated for different nebulizers. The total efficiency which includes the efficiency of transfer the sample solution into aerosol and the ratio of fine to large droplets has been studied. Three of the most common used pneumatic nebulizers in the fields of emission, absorption and fluorescence spectroscopy were investigated. The used nebulizers were the commercially available concentric, cross-flow and the Babington manufacturer types. The measurements showed that the concentric nebulizer produced the smallest aerosol droplet size and the highest efficiency than the other nebulizers.

### INTRODUCTION

One of the weak links in analytical atomic spectrometry continues to be sample introduction. The efficiency of the nebulizers is usually lies in the range of 5-10%[1]. The limitations noted above have stimulated the search for better, more efficient nebulization systems.

In work with these devices large drops are removed from the streams (to waste) allowing only droplets of a very small diameter ( $< 10 \mu\text{m}$ ) to pass into the plasma as aerosol[2].

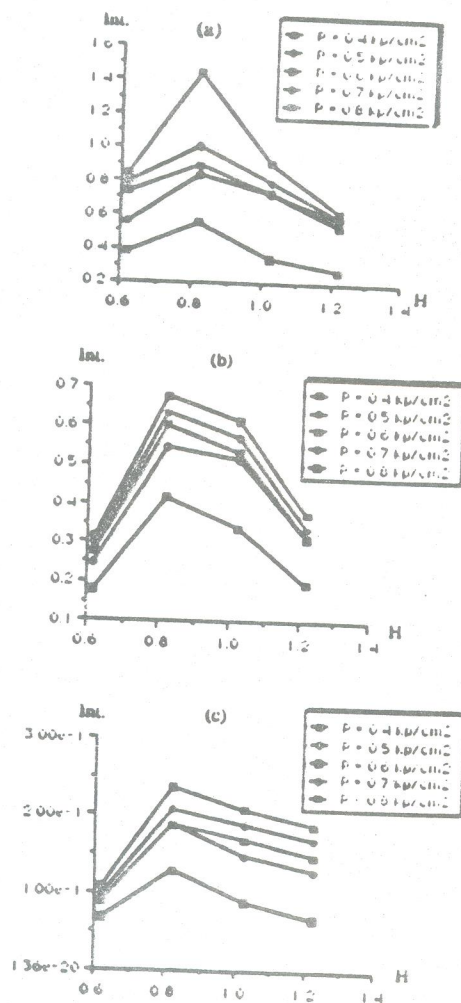


Fig. (2): Laser Scattering intensities at different heights and of different gas-pressure for nebulizers

- a- Concentric nebulizer.
- b- Cross flow.
- c. Babington nebulizer.

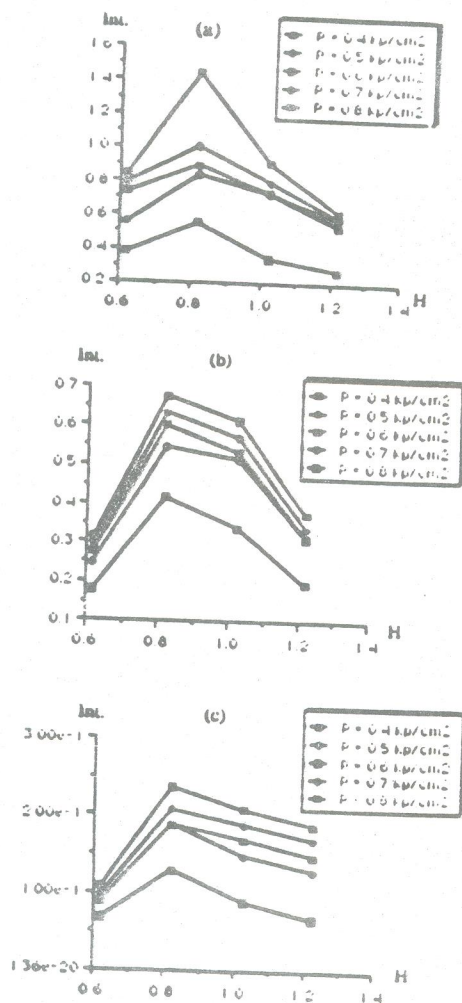


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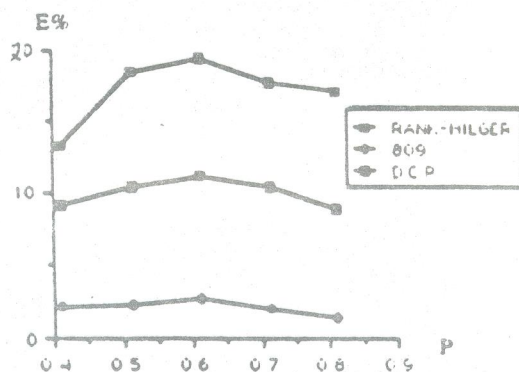


Fig. (3): The transfer efficiency at height 0.8cm, for the three nebulizers at different gas pressure

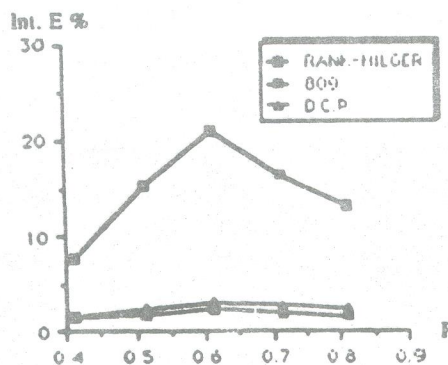
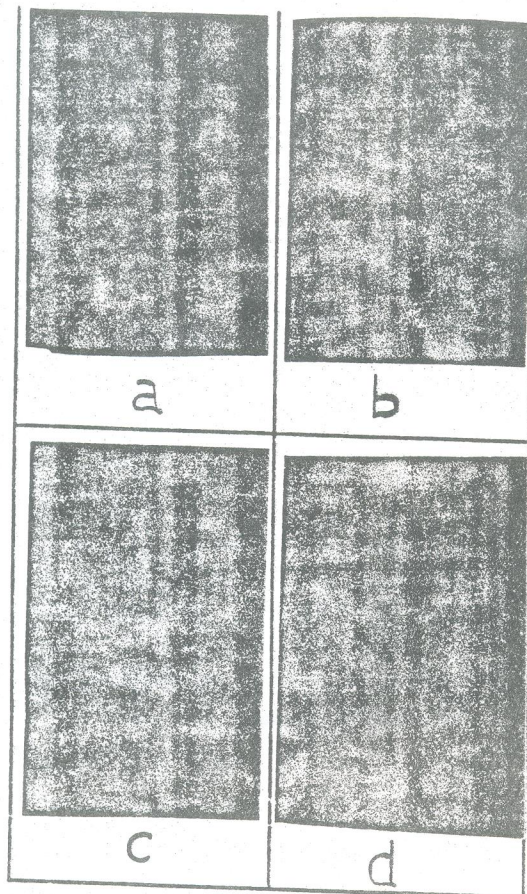
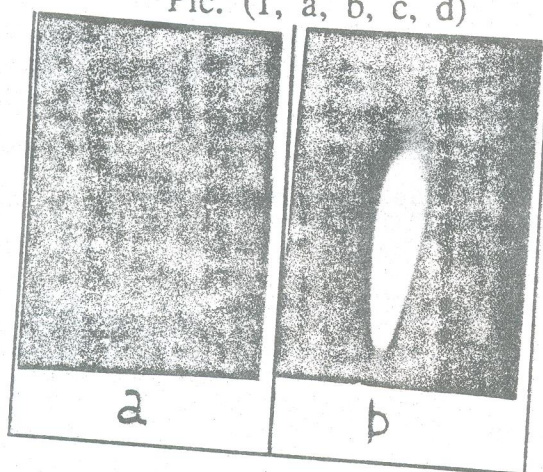


Fig. (4): The total efficiency at height 0.8cm, for the three nebulizers at different gas pressure.



Pic. (1, a, b, c, d)



Pic. (2, a, b)



## تقييم كفاءة البخاخات عن طريق دراسة تشتت ضوء الليزر بواسطة الرزاز الناتج عنها ودراسة توزيع جسيمات الرزاز حسب حجمها

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بالرغم من التقدم الكبير فى أجهزة التحليل الطيفى فلا زالت هناك مشكلة تؤرق الباحثين فى هذا المجال على مستوى العالم وهى ضعف كفاءة البخاخات المستخدمة فى جميع أجهزة التحليل والتى لا تتجاوز مستوى ١٠% مما جعل موضوع تطويرها هو الشغل الشاغل لعدد من الباحثين ، ويسبق التطوير دائما بناء أجهزة للمعايرة والقياس . ومن هذا المنطلق قام الباحثون بتصميم وتنفيذ جهاز لقياس شدة الضوء المتشتت من شعاع (هيليوم - نيون ) ليزر سمكه ٢ مم سلط ليمر خلال الرزاز الخارج من فوهة أنبوية سمكها ٤ مم ليمر عند منتصف الرزاز الخارج من فوهتها ، ويتم تجميع الضوء المتشتت على مدخل محلل ضوئى Monochromator مضبوط عند الطول الموجى لليزر المستخدم (632.8nm) متصل بأجهزة لقياس شدة الضوء .

استخدمت فى هذه الدراسة بخاخات لإنتاج الرزاز وهى الأكثر شيوعا فى أجهزة التحليل الطيفى وهى البخاخ المحورى المستخدم مع جهاز الإمتصاص الذرى "Rank-Hilger Atomspek H1580" والبخاخ العمودى المستخدم مع أجهزة مقياس اللهب "Carl Zeiss Jana" وبخاخ بابنجتود .

المستخدم مع جهاز بلازما التيار المستمر  
"Beckman Spectrospan V"

وبناء على ذلك تم بناء الجهاز ودراسة توزيع جسيمات الرزاز حسب حجمها عند معدلات تدفق مختلفة وعلى إرتفاعات مختلفة من فوهة أنبوية الرزاز للبخاخات المختلفة . كذلك تم دراسة الكفاءة الكلية للبخاخات التى تعرف بأنها حاصل ضرب كفاءة التحويل من سائل الى رزاز مضروبا فى نسبة الجسيمات الدقيقة إلى الجسيمات الكبيرة كما تم تصوير الرزاز بواسطة ضوء الليزر والضوء الأبيض فوتوغرافيا فى الوضع العمودى وعند زاوية ١٢٠° وقد وجد إن البخاخ المحورى ينتج رزاز أقل حجما وأكثر عددا من البخاخات الأخرى عند ارتفاع الرسم من فوهة الأنبوية وعند ضغط غاز ٦ KP/Cm<sup>٢</sup>

Since in a steady flame of a uniform temperature and composition, all droplets having the same initial diameter will completely desolve at the same height in the flame, while droplets with different initial diameter will desolvate completely at different levels. In other words, by knowing the droplet size distribution above the burner surface, one knows the height distribution of the analyte concentration at the point of observation[3]. Knowledge of atom distribution in plasma, is of ultimate importance. It provides not only the basis for plasma diagnostics and signal prediction, but also a guide lines for systematic optimization and modification for sensitivity enhancement and interference reduction[4].

The nebulizer efficiency, the gas flow rate and the solution flow rate, play the important role in the formation of the optimal aerosol[5].

The performance of the nebulizers was usually evaluated with laser scattering measurements[6-8]. In the present work a laser scattering system was built. The efficiency of the three of the most common used nebulizers in the field of emission, absorption and fluorescence spectroscopy namely. Cross flow, Concentric and the Babington were investigated under different conditions.

Nebulizer total efficiency represents the resultant of two main factors namely; the transfer efficiency of the sample solution into aerosol and the density of produced fine aerosol particles. The aerosol particle size density has been measured by laser scattering, while the sample transfer efficiency was measured as:

$$\text{Transfer efficiency \%} = \{(w_p - w_d) / w_p\} \times 100$$

Where:

$w_p$  is the sample pick-up rate.

$w_d$  is the drain collection rate.

### Experimental Arrangements

The laser scattering system for investigating the aerosol particle size and consequently nebulizers efficiency has been built as shown in Fig (1). Using the available components in our laboratory as follows; the Oriffin Helium Neon laser source ( $\lambda = 632.8\text{nm}$ ), the (Zeiss PM3) monochromator and the (Kikusui Inter. Corp. Mod. cos 5021) oscilloscope. The latter is used as a photomultiplier preamplifier and as a signal monitor. The output signal was readout on the (Dynascan Corp.) electronic multimeter. The (RCA 931) photomultiplier was used. Its base, house and electronic network have been constructed in our laboratory as recommended by the manufacturer (Alfred Neye Enatechnik GmbH). The high voltage needed for the photomultiplier was supplied from (Leybold) power supply (-3000 - + 3000) V. The used nebulizers were the cross flow (Carl Zeiss Jena) Glass nebulizer where the concentric nebulizer is that typically used with (Rank Hilger Atomspek. H 1580) and the manufacturer Babington nebulizer is that typically used with direct current plasma (Beckman Spectrospan V).

The open-geometry spray chamber has been chosen because of its higher sensitivity [9,10,11]. The junction between the spray chamber and the burner base was elongated (15 cm) in order to select the most fine droplets of aerosol.

Double distilled water samples were used throughout these investigation. The intensity of light scattered at  $90^\circ$  from an incoming laser beam was measured. The aerosol was forced out of the end of a 4 mm (inner diameter) tube, and the 2mm diameter laser beam was passed through the centre of the aerosol column, at laser wavelength of 632.8 nm. Significant scattering at  $90^\circ$  is obtained only from particles which exhibit Rayleigh scattering. This scattering of He-Ne laser occurs only for particles in the (0.1-1  $\mu\text{m}$ ) diameter range [7]. The scattered light intensity is directly proportional to the square of the volume of the particle [2].



## RESULTS AND DISCUSSION

The intensity of the scattered laser from different positions " in the aerosol at different air pressures have been investigated for the three types of nebulizers, as shown in Fig (2 a-b-c). The rim of the aerosol tube has been taken as the zero level.

The curves in the above figures indicated that the intensity of the scattered laser increased as height increased until it reached a maxima at about 0.8 cm above the tube rim in all cases. After this maxima the intensity decreases gradually. Fig (2 a-b-c) shows also the relationship between the scattered intensity and the gas pressure. The intensity increased as the pressure increased until a maxima at  $0.6 \text{ kp/cm}^2$ . Then decreased by further pressure increase.

This behaviour indicated that the fine aerosol droplets have a distribution with maximum density at  $0.6 \text{ kp/cm}^2$  and 0.8 cm height. The observed results may be attributed to the interaction between the factors affecting the particle size distribution which are not only the gas pressure and the inner diameter of the tube (which determines the initial velocity of the droplets at the zero level), but also the angle by which the droplet leaves the tube rim, and the viscosity of the aerosol due to the friction between the particles of different velocities, the collisions between the particles and the gravitational forces. The resultant of the interaction of these factors on the droplet size distribution arranged the droplets of the same size at the same height.

The photographic pictures taken for the scattered light from the aerosol, at pressures 0.5,  $0.6 \text{ kp/cm}^2$  (pic, 1 a, b.) at  $90^\circ$  and (c, d)  $120^\circ$  with the illuminating laser beam, give a real evidence that may prove the above mentioned particle size distribution assumption.

In picture (a,b) the observed clear distinguished zones with different colour intensities and areas indicates that all sorts of droplets having the same particle size are located at the same height. The area and the colour intensity of the different zones increased upwards until a distinct zone, and then decreased having the same character as previously observed in the laser scattering measurements.

D.R. Wiedenn and R.S. Houk [12] studied photographs, of the aerosol produced by similar nebulizers, they found that there are maximum densities of fine droplets at a certain height, which in general agreed with our results.

Further study of the scattered light intensity curves Fig ( 2 a-b-c ) at the preferable height of 0.8 cm for the different gas pressure showed a maxima at pressure 0.6 kp/cm<sup>2</sup>. Above this value no further increase was indicated, i.e, high density of the finest aerosol droplets takes place at this pressure and that height. This observed decrease in the scattering signal for the higher gas flow rates may be due to dilution of the aerosol, not to a change in the aerosol generation rate. According to G.F. Kirkbright [5] when high gas flow rates are employed a greater fraction of large droplets are produced inside the aerosol chamber, which do not remain suspended as an aerosol.

Picture (2.a,b), taken for the aerosol, using white light, at pressure 0.6 kp/cm<sup>2</sup> at two different positions (a) at 90° with the illuminating beam and (b) at 120°. Photo (a) represents the scattered light produced by the fine aerosol mist. The intensity of this photo is relatively faint and occupies the central region above the tube rim in comparing with the more bright picture (b) of reflection.

These pictures showed that the nebulizer efficiency does not depend upon the sample transfer efficiency only, but also upon the ratio of the fine to the large droplets.

The fine droplets, were found concentrated in the central region following a droplet size distribution pattern having its maximum value at about the midpoint of the aerosol height where the large droplets, occupied the outer aerosol envelope. This may be due to the centrifugal forces, since the aerosol was feed lateraly at the tube base.

The relationship between the conversion efficiency and the gas pressure of the three nebulizers is shown in fig (3). The conversion efficiency was measured on the basis of the equation mentioned in the introduction part. The Rank-Hilger nebulizer was found to be the best one in converting the solution into aerosol, its efficiency reached 18.3% but the D.C.P. is only 10.6 % while the worset one was the glass nebulizer with efficiency 2% only. Total efficiency was measured as the product of the conversion efficiency and the laser scattering intensities. Since the intensity of the scattered laser is related to the fine droplets density of the aerosol. Fig (4) shows the relationship between the measured total efficiency and the gas pressure as the scattered laser is measured 0.8cm above the tube rim. All curves have the same behaviour; they increased until maximum at pressure  $.6 \text{ kp/cm}^2$  and then decreased steadily.

In comparing the total efficiency curves fig(4) with the nebulizer converting efficiency curves fig(3); one can clearly noticed that they have the same overall shape but with a remarkable change in their relative intensities. Thr Rank-Hilger total efficiency maxima increases by about 11% over its converting efficiency, this increase can be attributed to the composition of the produced aerosol, where the fine droplets density exceeds the large droplets by about this ratio, while in case of the other two nebulizers, the ratio is reduced to great exstent.

Generally, the present work provided a quantitative procedure to judge the performance of any manufactured type of nebulizers and also can evaluate any new home made designed ones. This can help the stimulated research for better nebulizer which is still the task of many researchers all over the world.



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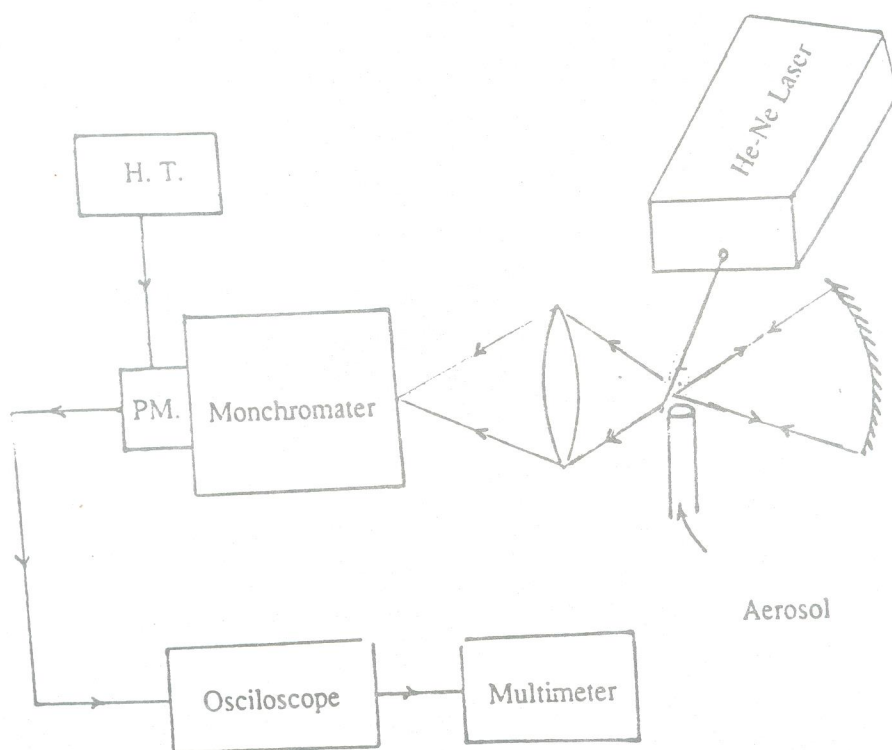


Fig. (1): Schematic diagram of the laser scattering measurement apparatus