ISSN 2250-3153

Estimate some of the aerodynamic characteristics of urban areas by using wind tunnel

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Abstract- The aim of this study was to calculate the drag coefficient (Cd) , surface roughness (Zo) and friction velocity (U_*) these characteristics are very imported in (urban planning, pollutants diffusion, Wind Energy) these characteristics are calculated depended on a series of wind tunnel Experiments to different obstacles type, We has used eight type of obstacles Such as Staggered arrays and Regular arrays and with different geometric shapes like a Diamond and cubic. several of empirical equations has been estimated, these equations can be used in urban areas under neutral weather conditions .

Index Terms- friction velocity – drag coefficient – surface roughness – wind tunnel .

I. INTRODUCTION

The aim of this work is to try to study and analyze the Aerodynamics characteristics of urban surface to conclusion equations to calculate the each of the surface roughness (Zo) and the drag coefficient (Cd) by depends on different obstacles(in height, Homogeneity height and distribution of the various models) By using wind tunnel device. The aerodynamic characteristics are very important in the study of the environment, estimating evapotranspiration values, estimating the efficiency of wind power, transport of pollutants and weather modifications in cities.

There have been many attempts to study the aerodynamic characteristics of urban arrays , for example Sheikh Ahmed Zaki et al.(2014) Where they tried to estimate the drag force and effective pressure on the walls of buildings by using wind tunnel[1]. and Wieringa (1992) where he study the surface roughness and its transactions in a homogeneous area, and he estimation the value of the length of the displacement length (Z_d) as well as distance affecting wind flow (Fetch) has estimated the researcher roughness over different surfaces[2].and Grimmond et al. (1998) Who has studied the nature of the effect of roughness on the movement of air near the ground surface in urban areas [3]. Macdonald et al.[4],Lettau [5] , Counihan [6] , Raubach [7] and Rotach [8] introduced simple mathematical expressions to determent(Z_0)and (Z_d)based on the frontal area density λ_f and plan area density λ_p.

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II. Theory

Consider that you are putting your hand or plate flat surface out of the car window as it moves, so that the flow of air perpendicular to the plate, the total force acting on the plate as possible be given in terms of the following definition where the force acting based on body shape and characteristics of the fluid flow (turbulent and / or laminar flow) and these effects are imposed by the presence of known factor (aerodynamic coefficient) or called drag coefficient (C_d). In general, the drag force (f) is given as follows [7].

$$f = qACd \ldots\ldots\ldots\ldots\ldots (1)$$

$$f = \frac{1}{2} Cd\boldsymbol{A\mathcal{P}u^2} \ldots\ldots\ldots\ldots (\mathbf{2})$$

So equation (1) = equation (2)

When (A) is the Frontal space of obstacles in front of the wind direction, (u) is the wind speed, and ($\mathcal{P}$) is the air density. The shear stress ($\mathcal{T}$) has a clear relationship with the drag coefficient shown in the following equation [9]:

$$\mathcal{T} = \frac{f}{A} = \frac{1}{2} CD\mathcal{P}u_{20l}^2 \ldots\ldots\ldots\ldots\ldots (3)$$

If (L) is the average height of obstacles, u_{20l} is the wind speed on twenty times more than height (L).

On the other hand, the shear stress ($\mathcal{T}$) can be written as the following equation :

$$\mathcal{T} = \boldsymbol{\mathcal{P}u_*^2} \ldots\ldots\ldots\ldots\ldots (\mathbf{4})$$

Then from equation (3) and equation (4), we will Obtains the following equation:

$$Cd = \frac{2u_*^2}{u_{20l}^2} \ldots\ldots\ldots\ldots\ldots (5)$$

For friction velocity, it is defined as a function of the average of wind speed fluctuation in horizontal and vertical component ($\acute{u}$ and $\acute{w}$) It can be measured by the following equation [10]:

$$u_* = \sqrt{\left|\overline{u'w'}\right|} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

The surface roughness length (Z o) A very important factors affecting on the movement of winds in the surface boundary layer, we can measure (Z o) by the Logarithmic equation as follow [11]:

$$\ln(z) = \frac{K}{u_*} u(z) + \ln z_0 \ldots\ldots\ldots\ldots\ldots (7)$$

If we drew the relationship between u *(z)* on x - axis and ln (z) on y – axis then from linear regression (especially in the neutral weather conditions) the Slope of the regression line will equal to $\frac{k}{u_*}$.

In the other hand the intersection of linear regression line with the y-axis will equal to $ln(z_0)$, so Z_0 and U_* can be estimated from previous relationships.

III. Experimental set – up

1- Roughness surfaces

There were eight types of arrays involved in this study with different horizontal arrangement patterns, height variation, and element angles; we name it as in the following table

Table (1) the number and names of the types of arrays used in work and the concept of each one type

N	Name of type	concept of type
1	Ca1	Parallel arrays of cubic shape obstacles with homogeneous height
2	Ca4	Parallel arrays of cubic shape obstacles with In homogeneities height
3	Da1	Parallel arrays of cubic diamond shape obstacles with homogeneous height
4	Da4	Parallel arrays of cubic diamond shape obstacles with In homogeneities height
5	Cs1	Staggered arrays of cubic shape obstacles with homogeneous height
6	Cs4	Staggered arrays of cubic shape obstacles with In homogeneities height
7	Ds1	Staggered arrays of cubic diamond shape obstacles with homogeneous height
8	Ds4	Staggered arrays of cubic diamond shape obstacles with In homogeneities height

2-Instrumentation

The experiments were performed in a low speed open wind tunnel at the laboratory of the Mustansiriya University \College of Sciences \ Department of Atmospheric Sciences.the wind tunnel has consists of three parts ((contraction part 1m long ,1m high ,0.5m wide)(test part 2m long ,0.6 high , 0.5 wide)and (Diffuser part 1m long , o.8 m high ,0.5 m wide)) . The Area which are covered with roughness Amounted to (3×0.5) m. the wind speed has been measured by using Hot-weir anemometer.

ISSN 2250-3153

IV. Results and discussion

1- Drag coefficient C_d

The Figure {1-1} shows the highest value of coefficient drag (Cd) when type Ds1, the lowest value was recorded at type Da1.

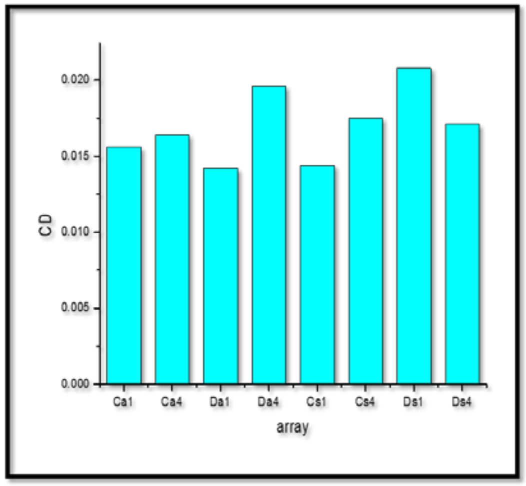


Figure {1-1}. Value of drag coefficient to different types of obstacles.

Results has shown(As shown in Fig {1-2}) that the relationship between surface roughness and the drag coefficient It has strong relationship and type of relationship is a linear direct proportion , The value of the correlation coefficient for this relationship was(R=0.8244),we can obtained empirical equation from this relationship as follow:

$CD = 0.0103 + (1.8713\times Z_0)$ … …(8)

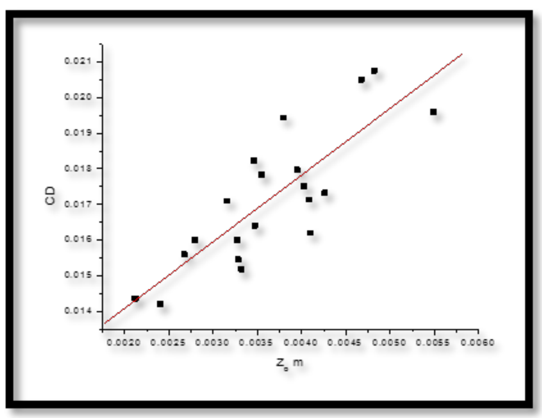


Figure {1-2}. The relationship between surface roughness and the drag coefficient

The relationship between drag coefficient (Cd) and friction velocity (U_*) (as shown in Fig {3}) indicated a strong correlation coefficient (R= 0.781) so we can obtained empirical equation from this relationship as follow:

$CD = -0.0111 + (0.0385 \times u_*)$ … … … … … (9)

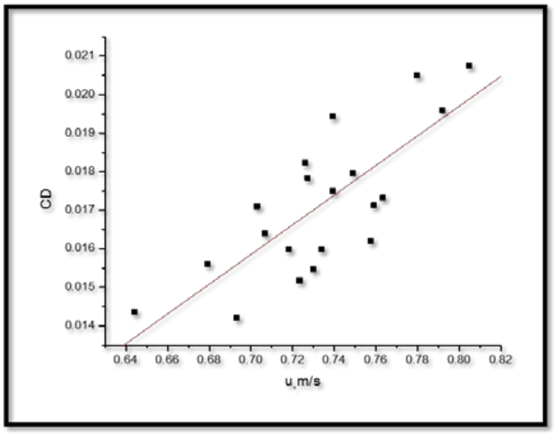


Figure {1-3}. The relationship between friction velocity (U*) and the drag coefficient (Cd).

The empirical equation to calculate drag coefficient (Cd) depending on the value surface roughness (Z_0) and friction velocity (U*) as follows:

$$Cd = \frac{(0.0004 + 0.9356 \times Z_o + 0.01925 \times u_*) - 0.00687}{0.6445} \dots\dots\dots\dots (10)$$

2 -Friction velocity (U*)

The Friction velocity (U*) has been measured and The Figure {2-1} shows the highest value of Friction velocity (U*) when type Da4, the lowest value was recorded at type Cs1

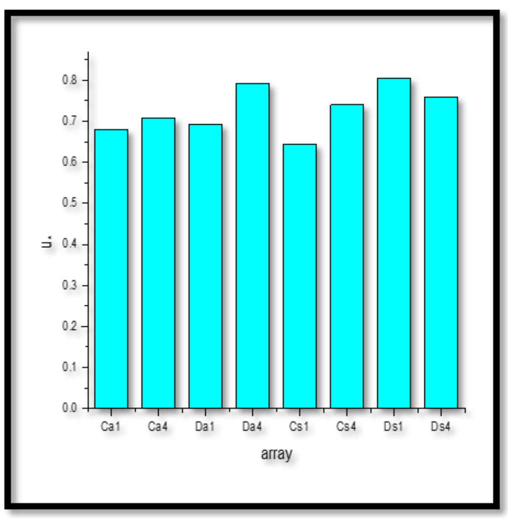


Figure {2-1}. Value of friction velocity (U*) to different types of obstacles.

3 -Roughness length

The surface Roughness length (Z_0) has measured and the Figure {5} shows the highest value of roughness length (Z_0) when type Da4, the lowest value at type Cs1.

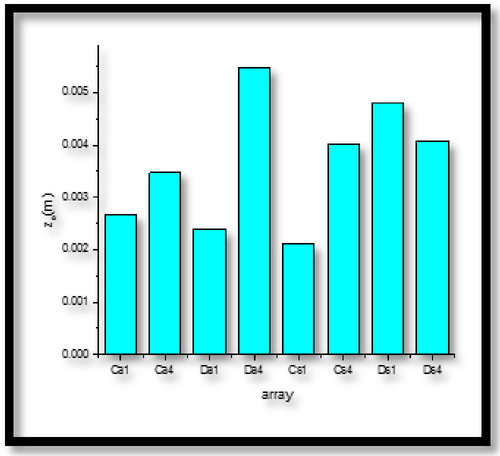
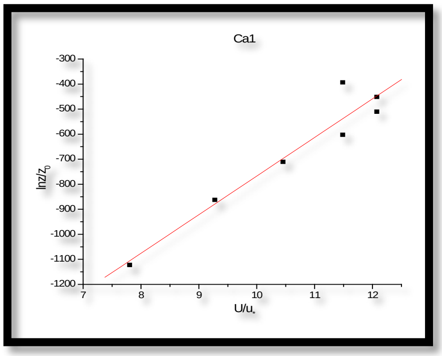


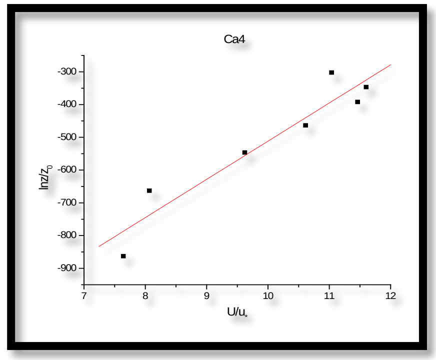
Figure {3-1}. Value of surface roughness (Z_0) to different types of obstacles.

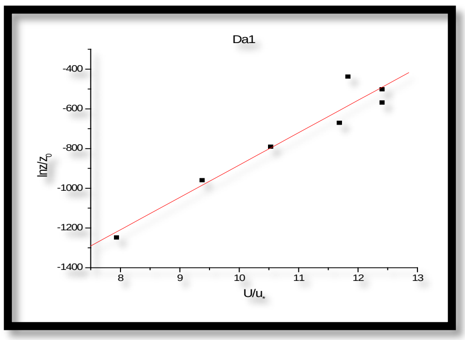
By estimating the surface roughness values of different patterns from the relationship between ln (Z/Z_0) and U (z) / U_* (as shown in table {3-1}) , we concluded the table (3-2), which includes empirical equations to calculate the surface roughness values (Zo) for different types of obstacles depending on the value of U_* , lnz and U (z) . The correlation coefficients of these equations are very strong (close to R=1)

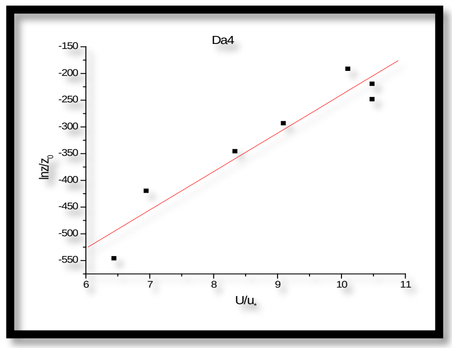
ISSN 2250-3153

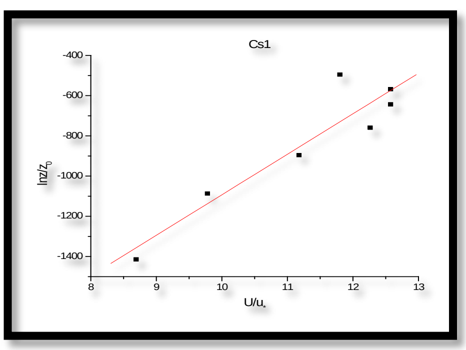
Table {3-1}. The relationship between ln (Z/Z_0) and *U (z)* / U_* to different types of obstacles.

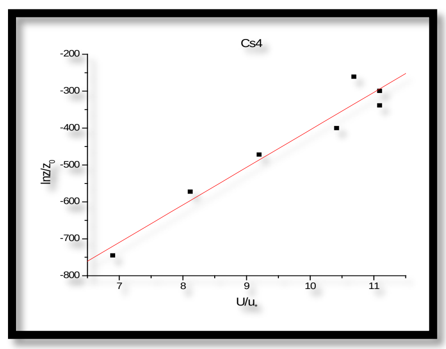


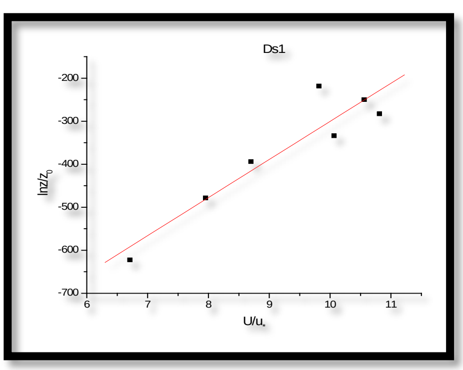


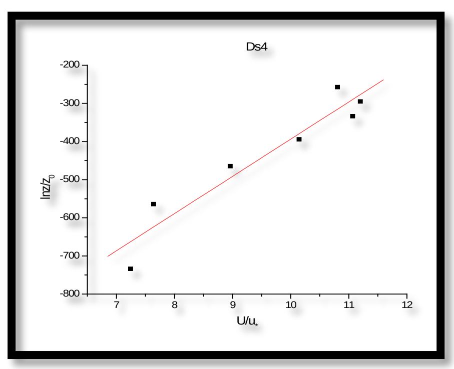












ISSN 2250-3153

Table {3-2}. The empirical equations to calculate the surface roughness values (Zo) for different types of obstacles and its correlation coefficients value.

N	Name of type	**correlation coefficients R**	**The empirical equations to calculate the surface roughness values (Zo)**
1	Ca1	0.9617	$Z_0 = \frac{\ln Z}{\left(154.1829 \times \frac{u(z)}{u_*}\right) - 2309.1948}$ ……………(11)
2	Ca4	0.9502	$Z_0 = \frac{\ln Z}{\left(116.6191 \times \frac{u(z)}{u_*}\right) - 1677.9492}$ ………. … . (12)
3	Da1	0.9658	$Z_0 = \frac{\ln Z}{\left(163.01573 \times \frac{u(z)}{u_*}\right) - 2513.094}$ …………. . (13)
4	Da4	0.9555	$Z_0 = \frac{\ln Z}{\left(71.828 \times \frac{u(z)}{u_*}\right) - 958.091}$ ………. ……… (14)
5	Cs1	0.9323	$Z_0 = \frac{\ln Z}{\left(201.3737 \times \frac{u(z)}{u_*}\right) - 3106.6164}$ …………. . (15)
6	Cs4	0.9701	$Z_0 = \frac{\ln Z}{\left(101.6813 \times \frac{u(z)}{u_*}\right) - 1421.6009}$ ……………(16)
7	Ds1	0.9338	$Z_0 = \frac{\ln Z}{\left(88.5966 \times \frac{u(z)}{u_*}\right) - 1186.2681}$ ……………(17)
8	Ds4	0.9534	$Z_0 = \frac{\ln Z}{\left(97.5659 \times \frac{u(z)}{u_*}\right) - 1369.3696}$ ……………(18)

V. Conclusions

The surface roughness length (zo) be affected by in homogeneities height (ZH) of obstacles in urban areas Larger than the effect of other morphometric variables (i.e. Larger In homogeneities height (ZH) means increase in Z_o value)

The drag coefficient (Cd) value depends on the horizontal dimension of obstacles, which is facing the wind in urban areas.

There is a strong relationship between the drag coefficient (CD) and surface roughness Z_0 (correlation coefficient for this relationship R = 0.8244) so we obtained an empirical equation Describe this relationship.

There is a strong relationship between the drag coefficient (CD) and friction velocity (U_*) (correlation coefficient for this relationship R = 0.781) so we obtained an empirical equation Describe this relationship.

Empirical equations has been obtained to calculate surface roughness (zo) with a very strong correlation coefficients, these equations can be used under neutral condition.

VI. References

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II. CONCLUSION

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

APPENDIX

Appendixes, if needed, appear before the acknowledgment.

ACKNOWLEDGMENT

The preferred spelling of the word "acknowledgment" in American English is without an "e" after the "g." Use the singular heading even if you have many acknowledgments.

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