Chapter V

DISCUSSION AND EVALUATION

The results from the experiment in the preceeding chapter has provided comprehensive relations among variables and some parameters which are criteria to study the phenomena of the PFD agglomeration rate in the fluidized bed. The following details will be the discussion on what are problems in this experiment outlined under: The effect of the air distributor's design on the fluidizing air velocity, The PFD feed rate, The rate of PFD dissolution by gasoline.

Further more, the evaluation of the result and emphasis on what this experiment executes are very interesting and they will be presented under: Gasoline feed (C) and number of agglomerates (N) correlations, Coordinate transformation, Agglomeration efficiency, Defection in agglomeration.

5.1 The effect of the air distributor's design on the fluidizing air velocity.

From table 4.2, it is observed that the superficial air velocity along the bed length was not uniform and deviated not more than 15% from average. It cannot be assumed whether this is satisfied or not because there is no reference showing how the uniformity of fluid in a longitudinal section is justified but it is deserved to say it gave no trouble in fluidizing the PFD bed because the bed flow smoothly and continuously with no obstrucle and this can be closely seen from the photos in fig 3.1 and fig 5.1. However, it can be explained that the depression in the uniformity of fluidizing air is effected by two factors. The first is the fluctuated induction of the surrounding air by the jet sprayed from the paint spray bottle into the mixing path of the air distributor. The jet sprayed from the bottle was controlled by air pressure which was kept over the required operating condition 4 kg/cm^2 and regulated manually to maintain the 4 kg/cm^2. which ofcourse sometimes went higher causing the unsteady induction. In addition,

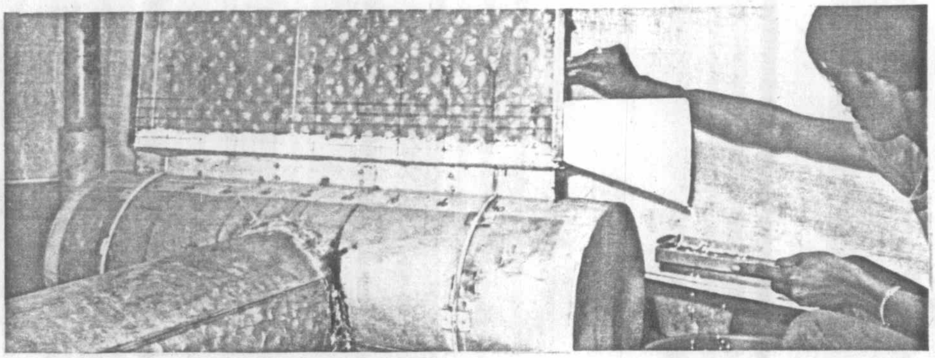

FIG. 5.1 PFD IN CONTINUOUS FLUIDIZING BED

in case of $d_p = 0.64$ cm. the air induced was not strong enough to fluidize the PFD bed to the height of 5 cm., so the blower was employed and caused the degree of unsteady flow higher. The second effect is the design of the air distributor which cannot follow the general design (13) that it recommends to have pressure drop across the distributor be 10% of the pressure drop across the bed with a minimum in all cases of about 35 cm.H_2O. The reason is that the distributor was not a close system, so even though, we can find a packed bed of which the pressure drop across the distributor is 35 cm.H_2O, the air was not able to pass through because there was a back pressure developed by the distributor against the input induced air which it may be assumed to be a resistance to the exceeding amount of fluidizing medium by the pervious distributor. If the bed was fluidized in a close system which means the fluidizing air was fed through the distributor by an air compressor not by induction of the jet stream, the uniformity of velocity along the bed might be easier controlled.

In addition, the minimum fluidizing velocity was observed as described in 3.3.1 and ensured by eq.2.12 which is a general equation that it was reliable. Besides that the calculation in appendix A.1 shows how eq.2.13 and 2.14 did not fit to determine the obtained experimental minimum fluidizing velocity by the unsatisfied boundary conditions. Table A.3.2 shows that equation 2.12 gives the best support to the result obtained, considered by means of the sum of square error, and it gives the minimum. Besides that the terminal velocity of all particle sizes are calculated as shown in appendix A.2 by description in 2.7.4. Both the minimum and terminal velocity are found out so that we would conduct the superficial velocity at the right way, that is, the superficial velocity must lie between them.

5.2 The PFD feed rate

Two feed rates of PFD for every particle size were conducted and from the result in fig 4.12 it shows that the PFD feed rate controls the relation between PFD particle size and gasoline amount. It can be noticed that the PFD feed rate was varied only 2 rates which is not enough to evaluate good experimental relations, the reasons that only 2 rates have been conducted are

1. At first, four various feed rates were performed, it was found that any feed rate and the next provided a series of relations quite similar and difficult to distinguish the curves. This can be noticed from the two series of curves obtained from the experiments shown in fig 4.12 which indeed were the first and the fourth rate and so if the rate was varied a little bit the series of the curves might be quite similar and difficult to identify which was in the same series.

2. The bed area is too small if it is larger the bed weight of PFD can be increased and the feed rate can also be varied more extensively.

5.3 The rate of PFD dissolution by gasoline mist

In this experiment, there is a significant parameter neglected because it is an unknown and quite difficult to study, it is the rate of foam drop dissolved by gasoline mist. If this rate was revealed the suitable retention time for PFD in the fluidizing bed can be calculated and the agglomeration will be more efficient.

The study to estimate this rate was omitted because it is doubtful to predict what model of dissolution of PFD by gasoline mist which may be called conversion, should be. The exclusive problems are magnified as follows:

It is foreseen that during the conversion which take place in the fluidizing bed, the drop may grow, shrink or remain unchanged in size. The average conversion of the stream of PFD depends on the rate of single particle conversion and the retention time. The problem aims at the rate of single particle conversion which may be predicted in two ways. The first is the continuous conversion that gasoline penetrates constantly through the whole foam drop with no resistance. The second is the conversion developed at the surface and then dry out resisting the gasoline penetration. Hence, we have six combinations existing BETWEEN grow, shrink or remain unchanged in size AND conversion with or without resistance. So, there are six probabilities to carry out one reliable result, this certainly causes high risk, consumes much time and great effort, and since it is believed the success of the study can be perceived without it, this part of study had been dropped out.

5.4 Gasoline Feed (C) and Number of Agglomerates (N) Correlations

There are six correlations in the experiment, showing the 1 linear relation verified by the least square method. The prediction of linear correlation was determined after 2 anticipations that it may be linear or exponential was evaluated by computer. It shows that the sum of square error from the linear evaluation is less than the exponential one as shown in Table 4.12. Fig 4.12 shows the different effects by feed rate and particle sizes on agglomeration. All the curves which are linearly related are extended and found they do not pass the origin as they should do because the unsteady rate of induced fluidizing air and the deviation of fluidizing velocity as described in 5.1. However, there is no evident that C VS N may possess the linear relation at the beginning in the range $C < 150$.

From the curves obtained in fig 4.12, it informs that the number of agglomerates, N, is varied directly with the amount of gasoline used, C, but inversely with the PFD feed rate, F, and the particle size, d_p.

$$N = f\left(C, \frac{1}{F}, \frac{1}{d_p}\right)$$

All these terms may be canbined to give an equation representing the agglomeration model of this experiment in many ways. The equation may be a simply conbining the three criteria with some additional terms or else a very complicate relation of several terms that it is not able to find out by this experiment because the phenomena involved comprises of Adsorption of gasoline by foam, Mass Transfer of the gasoline mist to the foam surface, Fluidization, Strength of polystyrene solution in different stage and age, Momentum Transfer of fluidizing particles and so on. Hence, in order to gain some advantages from the criteria we have, the N relation to the combining group of C, $1/F$, $1/d_p$ in term C/Fd_p will be found out. All data from table 4.6-4.11 are recruited and plotted point by point shown in fig 5.2. It is obvious that, if the scattered points are neglected, the points are densed in a tendency that a straight line can be drawn passing through them with the slope of 0.1583 allowing to have ± 42% deviation. That is N relates to $\frac{C}{Fd_p}$ linearly.

5.5 Coordinates Transformation

The relations of d_p VS N and d_p VS C are presented in order to assure that the N VS C relation obtained has been conducted in good attention. Fig 5.3a,b, and 5.3 c,d show the relation curves

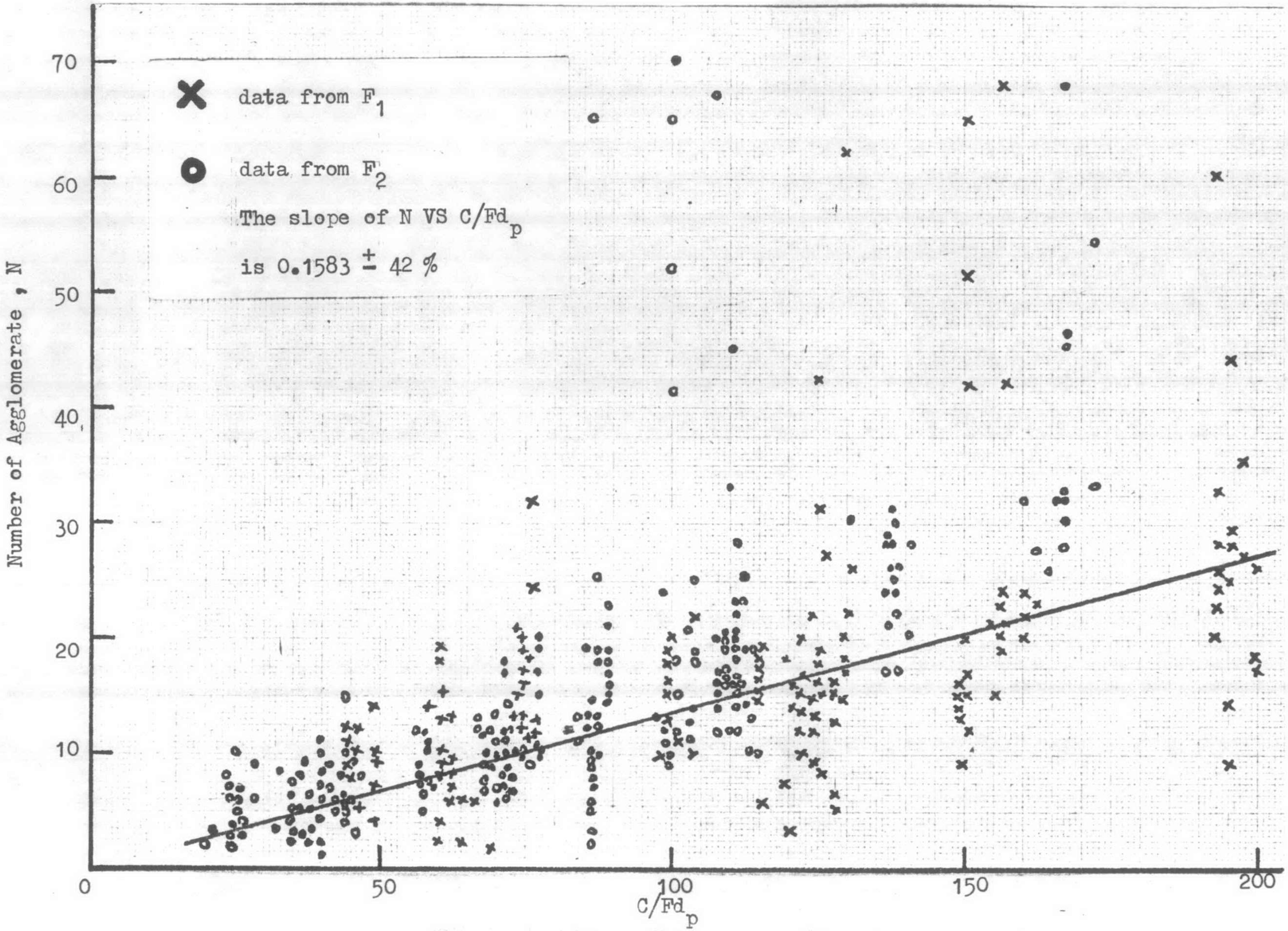

FIG.5.2 N VS C/Fd_p DETERMINATION

respectively. The curves are plotted by transform the variable parameters in fig 4.12 into the ordinates and vice versa, such as δ which was an ordinate is transformed into a family of curves related d_p VS N at various constant C in fig 5.3 a,b, for F_1 and F_2 respectively while d_p which was first a variable in the experiment is transformed into an ordinate.

The solid curves in these figures are plotted by transform the experimental N VS C coordinates of in fig 4.12 and the dotted curves are plotted by transform the coordinates of the same curves, same slope but assumed to pass the origin as discussed in 5.4.4 so the dotted curves give good order pattern of curves.

From fig 5.3 a,b it is obvious that the two family of curves behave the same pattern though at $C > 300$ the experimental curves deviate from the assumed curves. It shows that the smaller size of PFD increases the agglomeration rate faster than the bigger ones. because the slope of the curve at small d_p inclines more than that at larger d_p, so at the same increment of d_p, number of agglomerates increases faster when d_p is smaller. By similar transformation fig. 5.3c,d. is obtained in which the curves inform that

1. The bigger size of PFD lowers amount of agglomerates obtained by the same amount of gasoline.
2. Size distribution of large particle is less effected by the same gasoline increase to obtain the same agglomeration rate.
3. Higher rate of gasoline increase provides increasing agglomeration rate of any size distribution of particles

However, such informations can also be read out from the fig 4.12 and fig 5.3. From the tract of the curves in fig 5.3 a,b,c,d it seems that the gasoline amount over 300 ml/5 min affords good pattern of agglomeration.

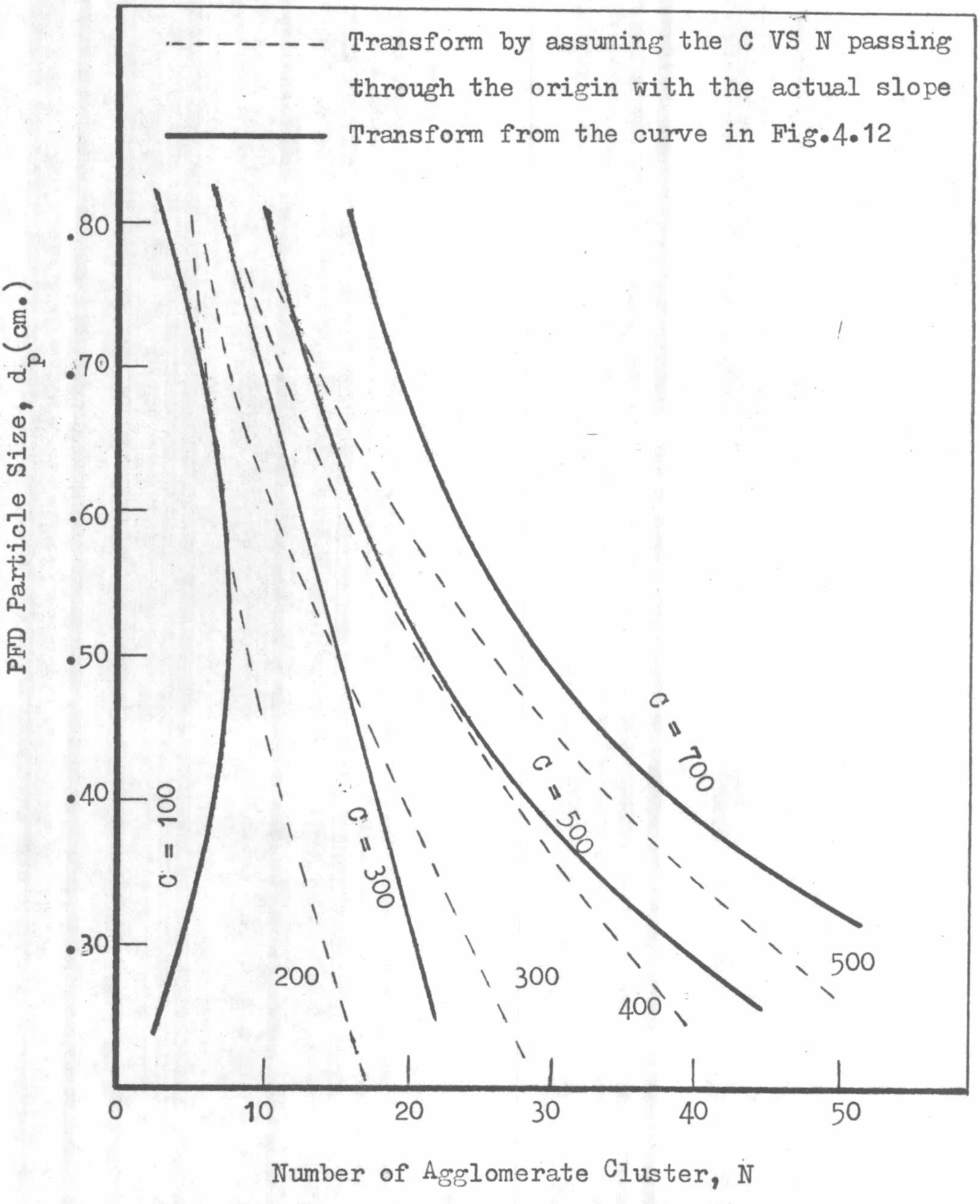

FIG. 5.3a. THE COORDINATE TRANSFORMATION FROM FIG. 4.12 TO d_p VS N FOR F_1.

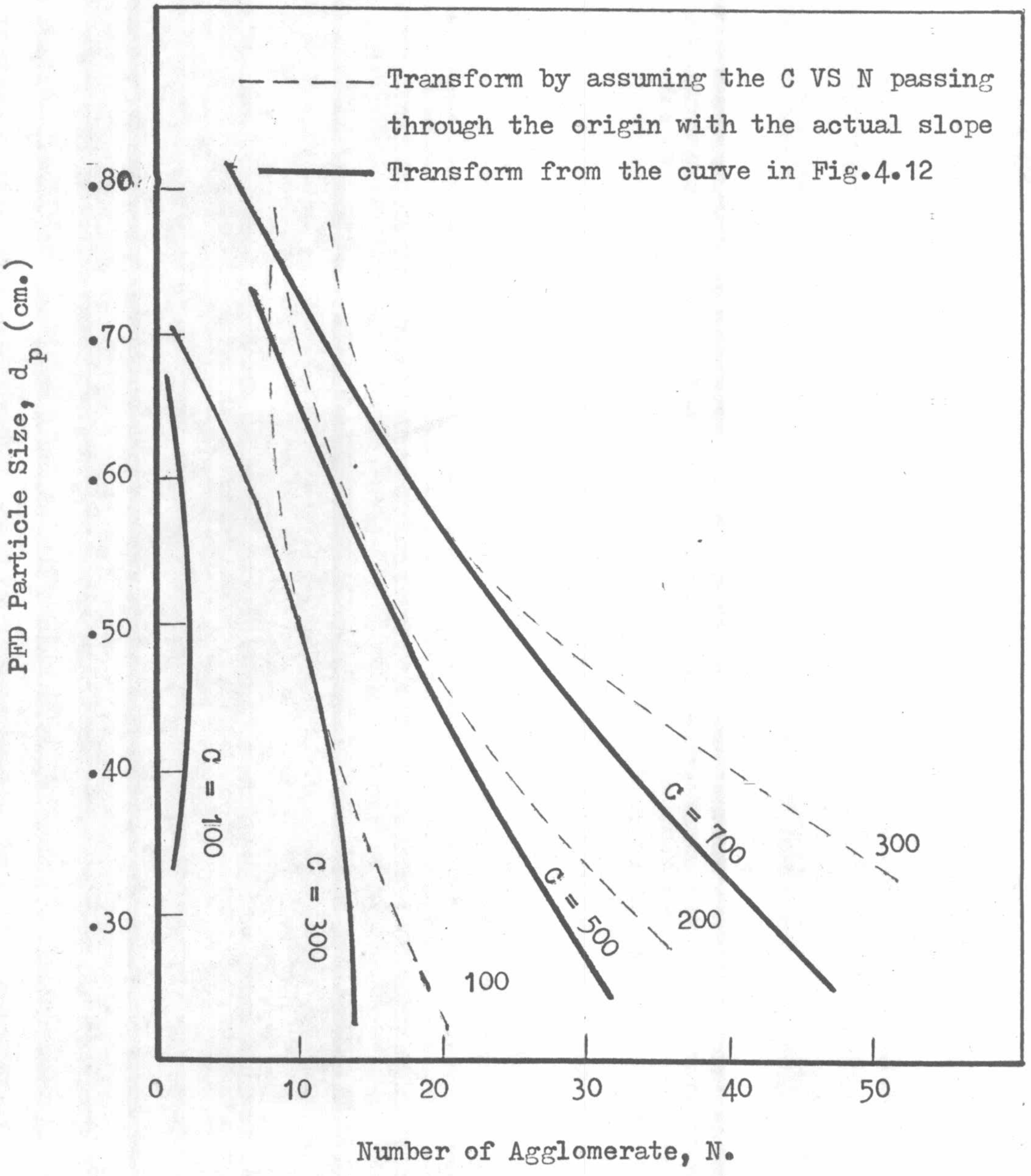

FIG. 5.3b. THE COORDINATE TRANSFORMATION FROM FIG. 4.12 TO d_p VS N FOR F_2.

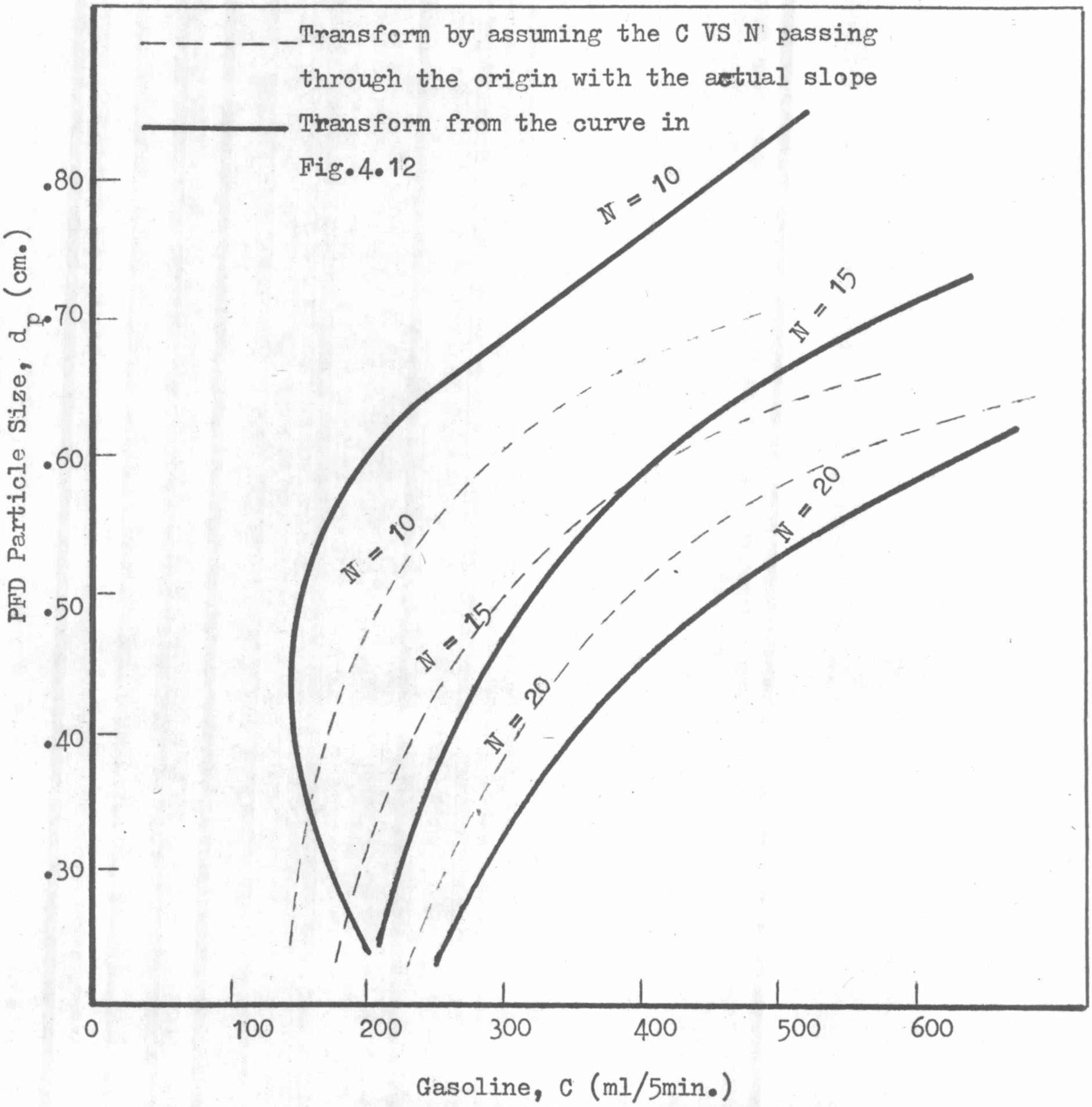

FIG. 5.3c. THE COORDINATE TRANSFORMATION FROM FIG. 4.12 TO d_p VS C FOR F_1.

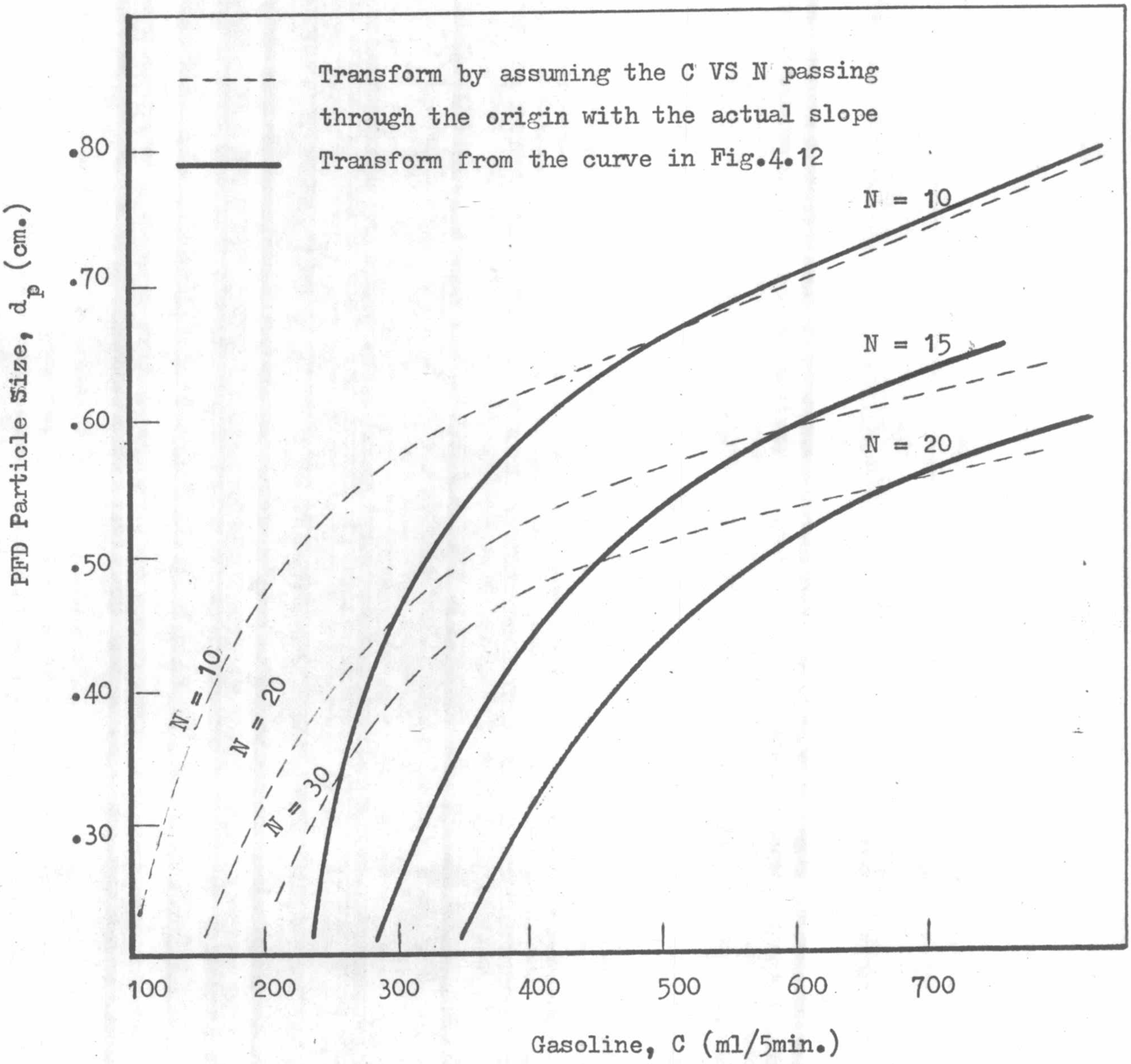

FIG. 5.3d. THE COORDINATE TRANSFORMATION FROM FIG. 4.12 TO d_p VS C FOR F_2.

5.6 Agglomeration Efficiency

The efficiency of agglomeration may be studied in various terms as follows:

1. Used gasoline for PFD agglomeration compares to the initial gasoline amount. This means requires the amount of gasline loss by flowing along with the fluidizing air, gasoline amount wastely dissolving PFD which gives no agglomerate and certairly are difficult to find out.

2. Weight of PFD agglomerates compares to the initial PFD feed weight. Though all the figures can be found out experimentally, it shows no good fitting to the system because the one important parameter, gasoline amount, has not been counted.

3. Comparison between the ratio of product or agglomerates weight obtained to the amount of gasoline used and the ratio of the weight of PFD to gasoline used to dissolve PFD to attain the sticky property so that it will be able to adhere to the other drops. The latter ratio, in other word, is the proportion of PFD and gasoline that gives the surface tension of polystyrene solution in gasoline= 28 dyne/cm. which can be found out in fig 4.4. From fig 4.4, it shows that the proportion or ratio allowing the 28 dyne/cm surface tension exists at 9000 mg PFD per 34 gm gasoline or at the ratio = 0.2647.

Before going into detail, the purpose of defining the term of agglomeration efficiency is to be explained. It is to find out how the experiment is proper evaluated and in some literatures, it is evalvated by the second means mentioned above which does not weight the very significant parameter, gasoline, the wetting agent that plays important role in agglomeration. Therefore, the third aspect will be followed.

Appendix B.2 shows the calculation following the third aspect and also the second means which the result is presented in Talbe 5.2 so that it will show how the third means, better and clearly, represents the evaluation of agglomeration. From table 5.2, by comparison in each

Table 5.1 Agglomeration Efficiency

② $$\% \text{ Agglomerate/Feed Rate} = \frac{\text{gm agglomerate}}{\text{gm.PFD Feed}} \times 100$$

③ $$\% \text{ Agglomeration Efficiency} = \frac{\left(\dfrac{\text{gm.agglomerate}}{\text{gm. gasoline used}}\right)}{\left(\dfrac{\text{gm. PFD}}{\text{gm.gasoline}}\right)} \times 100$$

σ=28dyne/cm

d_p	C	F_1	②	③	F_2	②	③
0.33	150	7.8	0.087	0.12	11.3	0.039	0.08
	250		0.119	0.10		0.067	0.08
	420		0.238	0.12		0.127	0.09
	520		0.366	0.16		0.152	0.09
	630		-	-		0.234	0.16
0.51	150	6.6	0.224	0.27	10.7	0.081	0.17
	250		0.471	0.34		0.134	0.16
	420		0.767	0.34		0.254	0.17
	520		1.226	0.44		0.362	0.20
	630		-	-		0.483	0.28
0.64	150	6.3	0.083	0.10	10.5	0.044	0.08
	250		0.340	0.24		0.072	0.10
	420		0.465	0.19		0.171	0.12
	520		0.472	0.15		0.253	0.14
	630		1.006	0.29		0.291	0.15
	730		-	-		0.472	0.19

particle size and feed rate, it is obvious that the value of efficiency at low C is higher and at high C lower than the value of the second means in every case. This should be reasonable and true because when the high amount of gasoline is applied through the fluidized bed in the same time interval, it contacts the same amount of PFD and certainly loses wastely with the air much more. In some way, though the higher C providing gasoline to contact more amount of PFD by its thicker mist, the gasoline increment dissolving PFD is still less than the amount of increasing feed. So, by weighting the loss gasoline in the evaluation, the % Efficiency increases with increasing C slower than the usual % Agglomerate per Feed Rate. Hence, the agglomeration efficiency is well defined and should be acceptable. It is also disclosed that the PFD size 0.51 cm provides best agglomeration with 0.44% efficiency by applying PFD feed rate 6.6 gm/min. with gasoline 104 ml/min. which is also confirmed by the value of % Agglomerate per Feed Rate.

By averall, the efficiency is quite low because,

1. The amount of PFD in bed was not enough to be contacted by gasoline which it can be improved by expanding the bed width so that more PFD will be retained
2. The PFD retention time in the fluidizing bed was too short. The lower feed rate allows better efficiency, but it must not be too low because the bed will be clogged by sticky particles that contact too much gasoline.
3. The gasoline passed through the bed too fast while flowing along with the fluidizing air. This should be controlled by decreasing the air velocity but this would irritate the height of fluidizing bed. The best way is to decrease gasoline amount.

5.7 Defection in Agglomeration

Three forces involving in agglomeration, they are

1. The shear stress distribution on the particle surface

exerted by the fluid flowing around the particle. It is momentum flux distribution or pressure distribution on particle and has been shown in appendix C.4

2. Agglomerating strength exerted by sticky surface of PFD that holds particles to adhere to each other by pendular strength at first and after that develop to be capillary strength as described in 2.6.2. The calculation of the both strengths are shown in appendix C.5 and C.6
3. Momentum of particle collision. This effected the agglomeration positively and negatively at the same time because it may assist particles to stick together or else break the agglomerates

Table 5.3 shows the value of various strength and terms participating in agglomeration. It is obvious that the pendular strength for agglomeration is very much higher than the momentum flux distribution on particle surface which means that agglomeration should occur very easy and much agglomerates are obtained, but in the experiment it was not so, the agglomeration efficiency is quite low and is not comparable. It may be predicted that the last term we have not counted, the momentum of particle collision, has played a very important role on agglomeration. It may be understood that the momentum flux distribution (F_t) associated with the momentum of collision overcome the agglomerating pendular strength (i_p). In calculation, momentum of collision has no identicle unit as F_t (momentum of collision's unit is gm.cm/sec) so it can't be shown by figure how the pendular strength is dominated, but it will be described by table 5.3

The maximum number of collision presented was found from the terminal velocity as shown in C.3 because the actual particle velocity in the fluidizing state was not known. It is shown here just to be an idea for explanation. Any particle collision provides momentum and the momentum strength depends on direction, area of collision, velocity and weight of particle. For a single sticky PFD that collides the other one, a good oriented or the center to center direction certainly boosts the pendular strength of the sticky polystyrene, but the misdirection of the collision does not assist its sticky surface to form agglomerates. In term of probability, the center to center direction of collision does not occur so easy, so it has rather a great possibility that the pendular strength of the agglomerate is reduced by colliding momentum and some particles may loss to aggregate but some may develop pendular strength to capillary strength weakly that may be broken away by next collision.

For the sticky agglomerates holding by pendular strength still require more gasoline to dissolve themselves for stronger strength by reaching the surface tension at least 23 $dyne/cm^2$ which is assumed to be the lowest effective strength of surface tension* and by the same time it has to collide the other clusters so very few of agglomerates are survived. It may be conclusively explaind that the collision rather depresses than fertilizes the agglomeration because it is obvious that at the instant the fluidization begins, collision plays its role before the sticky surface can develop the effective stickiness which takes time and a certain amount of gasoline and though the sticky PFD collides the others, it has very little chance to consort other particle and in the same time the momentum of collision has also a great

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* Refer to 4.3 the reasons to anticipate that the effective surface tension begins from 23 dyne/cm are

1. Beyond this point, its surface tension increases slowly which allows the chance to attach the other by its more sticky surface greater than those before this point
2. The probability to find a PFD possessing surface tension more than 23 dyne/cm is greater because before this point it increases rapidly

Table 5.3 Various Terms Participate in the Agglomeration

d_p (cm)	F_t $\frac{gm.cm}{sec^2}$	① $p = \frac{F_t}{A}$ (dyne/cm^2)	② i_p (dyne/cm^2)	③ i_e (dyne/cm^2)	④ Max.no.of collision per second
0.33	.2384	.6965	158	1099	571
0.51	.7754	.9485	96	746	582
0.64	1.553	1.191	75	6000	696

① From Appendix C.4
② " C.5
③ " C.6
④ " C.3

chance to break down the strong agglomerates.

In order to gain advantages from the gasoline that lost with the fluidizing air, it might be worth to form a multistage of fluidizing beds. The bed might be in other geometry such as a round shape and if one desires a more elaborate, he may install a spiral baffle in that round shape bed where the feed will be introduced at the spiral center and the outlet will be at the spiral end. The spiral baffle increases the flow path and resident time. Similarly in the experimental longitudinal bed the baffle might be arranged transversally, but here it was not applied because the bed width was too narrow. Any geometrical bed can then be top up one by one to form a tower of multistage beds. In operation, for the non-round shaped bed, there may be effects of non-uniform distribution of fluidizing air, and poor fluidizing state occupied by fluctuation in density with channelling and slugging, hence the best way to simplify our experiment, a round shaped geometry should be practicle in any way. The experimental bed may be fluidized shallowly and the fluidizing air velocity has to exceed 1.3 U_{mf} for good mixing (13).

The principle to be applied for the design of the suggested multistage beds is the gas adsorption that deals with the mass transfer operations between the gasoline mist in the air and PFD. The gasoline for the time being is assumed to be soluble vapour absorbed by PFD and air is the solute-containing or rich gas enters beneath and fluidizes the beds. The PFD is enriched while flowing down the tower of multistage beds. and grows in size by sticking to other particles. The design of tower depends on (26) magnitude of the desired concentration changes and on the rate of mass transfer per unit of packed volume, material balances, enthalpy balances and on estimates of driving force and mass transfer coefficients.

To determine whether the number of beds is suitable, we should criticize on the optimum cost spent for the experiment or the industrial applications. The costs concerned are building cost and the operating cost of the tower and the efficiency of operation as well.