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# Variable Dispensing Capacity Screw Feeder Based Powder Dispenser: Improving the Design by Studying the Effect of the Hopper Side Wall Slope($\varphi_s$) on Performance of the Dispenser

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**Abstract**

*The variable dispensing capacity screw feeder based powder dispenser (VDCSFPD) is used for dispensing of the radioactive Zr-Mo powder into the glass column (GC) in the TCGP facility. For satisfying the demand of the customers for specific Zr-Mo powder, this dispenser was developed and is in use. It has been fitted with a hopper with a stirrer to break the stagnant mass of the powder to be dispensed stops flowing due to formation of the arch or the rat hole. Failure to flow occurs mainly due to moisture content and the favourable particle size in addition to the geometry of the hopper. But since the existing volumetric dispenser fitted with ultra high molecular weight polyethylene (UHMWPE) hopper (36° hopper angle) never used any kind of flow promotion device, Zr-Mo powder is free flowing (proved by tests on Zr-Mo powder) and so in case of VDCSFPD chances of no-flow condition shall not occur. With the objective of removing the stirrer from the hopper and to get highest achievable flow using the conical hopper, experiments have been conducted to select the most desired angle of the side wall slope ($\varphi_s$) of the hopper. The angle $\varphi_s$ of the hopper is decided by using the property of the angle of repose of the powder. The proposed paper highlights the result of the experiments performed by using hoppers having various values of $\varphi_s$ and the effect of it on the flow rate of the powder dispenser.*

## 1. Introduction

The VDCSFPD is used for dispensing of the radioactive Zr-Mo powder into the GC in the TCGP facility. For satisfying the demand of the customers for specific mass of Zr-Mo powder related to the radioactive content, this dispenser has been developed and is in use. It has demonstrated the ability to dispense the powder at the rate of 0.21g/s, thus solving the problem of non-uniform distribution of the powder. This dispenser has been fitted with a stainless steel hopper with a stirrer to break the stagnant mass of the powder to be dispensed. Powder stops flowing through the hopper due to formation of the bridging/doming, flushing and the rat hole (fig.1). Failure to flow occurs mainly due to favourable particle characteristics and geometry of the hopper (fig.2). Generally the Zr-Mo powder is bone dried and is free flowing. The existing volumetric dispenser fitted with UHMWPE hopper never used any kind of flow promotion device.

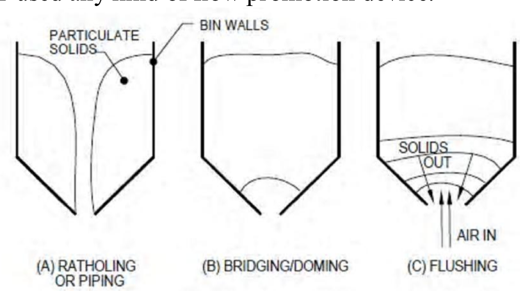


Fig.1

Also the coefficient of friction between the stainless steel and powder is less than between the UHMWPE and the powder. Therefore, in case of VDCSFPD chances of no-flow condition shall not occur. This sited the chance of improvement in the dispenser design by removing the stirrer. Since the stirrer is placed exactly concentric to the hopper exit, it acts as restricting component to the flow of the powder to the screw feeder. By removing the stirrer, it was thought that flow rate of the dispenser can be increased. With the objective of removing the stirrer from the hopper and to get highest achievable flow using the conical hopper, experiments have been conducted to select the most desired angle $\varphi_s$ of the hopper. The desired angle $\varphi_s$ of the hopper is decided by using the property of the angle of repose of the powder as a lower limit (36º) and the angle of slope of the UHMWPE hopper (72º) in case of volumetric dispenser as upper limit. The proposed paper highlights the result of the experiments performed by using specially fabricated stainless steel hoppers having various values of angle $\varphi_s$ and the effect of it on the flow rate of the powder dispenser.

## 2. Materials and methods

Rate of discharge from the hopper depends upon number of factors like bulk density, hopper angle, diameters of the hopper etc (fig.2). For mass flow type of discharge, for theoretical calculations, Johnson's equation is,

$$m = \rho^0 A \sqrt{B g} / (2(1+m)\tan(\theta))$$

Where, θ- semi included angle of the hopper,
m- Discharge rate,
$\rho^0$ – bulk density
A- Outlet area
B- Outlet diameter,
g – Acceleration due to gravity

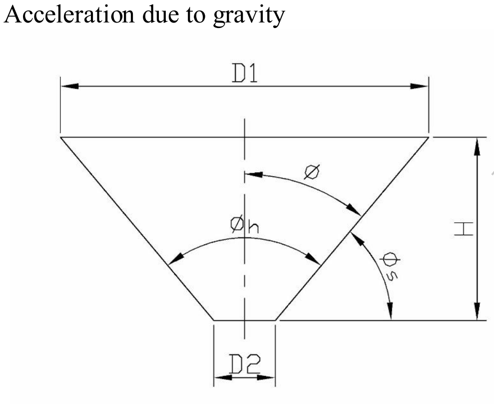


Fig.2 Hopper geometry

Since in this case, the hopper is one of the components of the machine, the characteristic of the screw feeder is controlling the actual flow rate. Since the hopper is feeding the screw feeder, actual discharge is affected by the characteristic of both the components. The capacity of a screw conveyor depends on the screw diameter, screw pitch, speed of the screw and the loading efficiency of the cross sectional area of the screw. The capacity of a screw conveyor with a continuous screw is generally expressed as :

$$Q = V.\rho$$

$$Q = 60.(\pi/4).D^2.S.N.\psi.\rho.C$$

Where,
Q = capacity of a screw conveyor
V = Volumetric capacity
ρ = Bulk density of the material
D = Nominal diameter of Screw
S = Screw pitch
N = RPM of screw
Ψ = Loading efficiency of the screw
C = Factor to take into account the inclination of the conveyor

In order to study this aspect, in addition to the objective of removing the stirrer and improve the rate of dispensing, following approach for has been followed in experiment-

1. Based on the past experience and Zr-Mo powder characteristics, fix the range of the hopper slope angle
2. Design and fabrication of the hoppers with different $\varphi_s$
3. Using the VDCSFPD assembled with the conical hopper having various $\varphi_s$, pass the Zr-Mo powder having different bulk density and record the rate of discharge.
4. Plotting the characteristic graph for selecting the most appropriate angle $\varphi_s$ of the hopper,
5. Design and fabricate the hopper for the most appropriate $\varphi_s$
6. Study the behaviour of the dispenser for the selected hopper angle $\varphi_s$ by passing the powder having different bulk density.

In order to select the best hopper angle $\varphi_s$ to be made from stainless steel, range of angle $\varphi_s$ selected for testing was from 36º to 72º. Accordingly design of the hopper was done for fix volume. A stand-by powder dispenser was designed and fabricated such that the hopper can easily be dismantled from it. Fabricated dispenser was exactly same as that used in production cell. Since the radioactive powder was not available for this experiment, it was decided to use the available inactive powder having similar properties to the active samples.

### 2.A Characteristics of the VDCSFPD with stainless steel hopper fitted with the stirrer [17]

VDCSFPD is a versatile dispenser commissioned in Geltech generator production facility of the BRIT at Vashi complex. In actual use it has given the delivery rate of 0.21g/s, thus helping in controlling the mass of the powder to be dispensed in the GC. Mass to be dispensed is controlled by using a DC motor for screw feeder through the timer. It has a stainless steel hopper with a stirrer for uninterrupted flow of powder. A study on the dispenser revealed results as shown in the fig.3.

During investigation of the powder dispenser, it is found that the stirrer which is rotating at 30RPM is controlling the flow rate by reducing the exit diameter of the hopper. Improvement in the flow rate through the dispenser was sited and was possible by removing the stirrer. This would considerably reduce the time spent in dispensing of the powder into the GC. Additionally, the complication imposed due to the presence of the stirrer and the motor driving it can be reduced by removing it.

## 2.B Experimentation

The proposed experiment involves design and fabrication of the hoppers having different $\varphi_s$ angles and using the VDCSFPD, study the flow rate. Additionally comparison between the flow through the available VDCSFPD with stirrer and the proposed one through hopper with changing slope angle to be done. Selection of the most appropriate hopper angle $\varphi_s$ will be done on the basis of general trend of the change of the flow rate. At last fabricate the hopper having selected $\varphi_s$ and study the dispenser for flow for different bulk density powders.

### II.B.a Experiment to select the most appropriate angle $\varphi_s$

For the constant volume and discharge diameter, the hoppers having different $\varphi_s$ values were designed. In a step-by-step approach, selected $\varphi_s$ angle started from 36º to 63º with a difference of 2º. After fabrication, it was found that due to fabrication difficulties, angle $\varphi_s$ is varying within a tolerance of 1 to 2º on either side. Therefore, the $\varphi_s$ angle of the hopper used for this experiment was found to be 36º, 38º, 40º, 41º, 44º, 47º, 51º, 55º, 56º, 63º. The machine used for this experiment has been designed for ease of dismantling and assembling of the hopper. Figures 4 show a powder dispenser with steeper slope angle of the hopper made from UHMWPE. It has been used with volumetric dispenser. This angle becomes the maximum limit for the hopper to be made from AISI304. Since the coefficient of friction between the Zr-Mo powder and UHMWPE is more than stainless steel, desired angle shall be less than 72º.



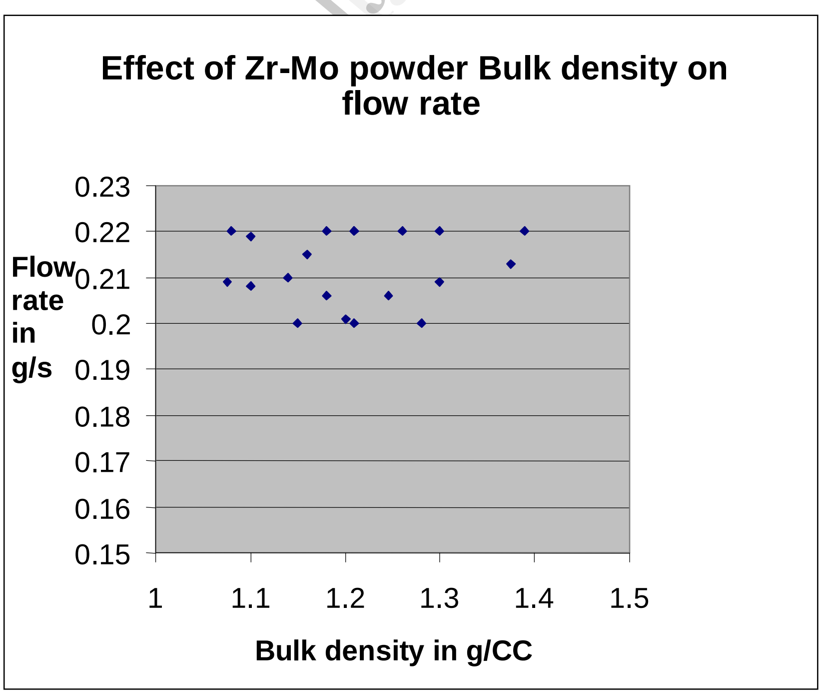


Fig. 3 Variation of the flow rate of the powder dispenser with bulk density

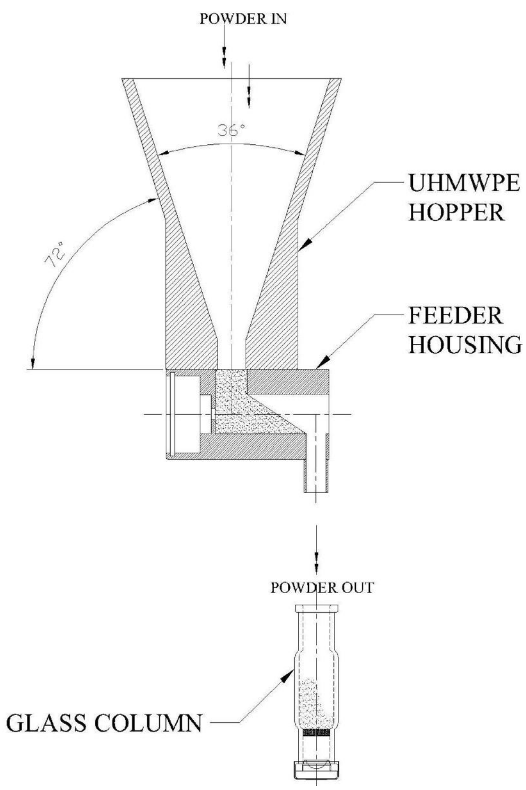


Fig. 4 The dispenser with steep angle $\varphi_s = 72^o$

Fig. 5 Experimental setup

Fig. 6 Electronic balance for measuring the mass of the powder and volumetric beaker

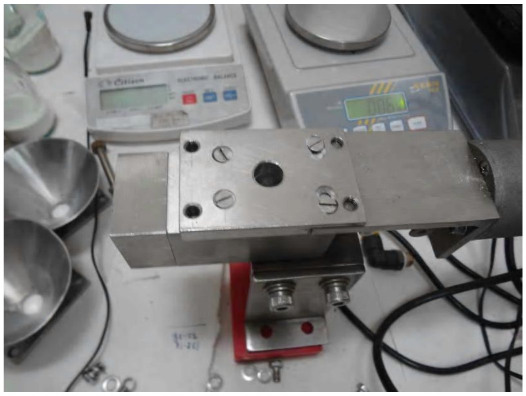

Fig. 7. Powder dispenser without the hopper

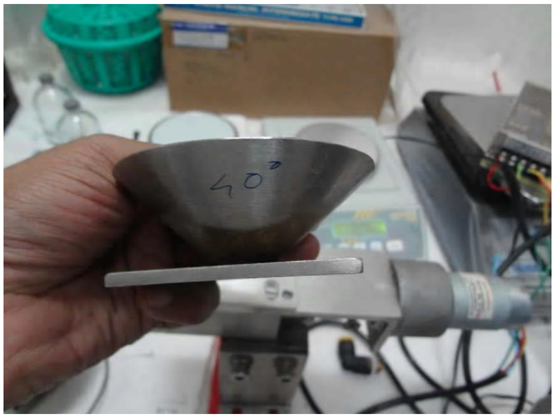


Fig. 8. SS conical hopper having $\varphi_s$ =40° ready for assembling with the dispenser


Fig. 9 Powder dispenser with conical hopper


Fig. 10. Timer used for measuring the time taken by the dispenser to deliver the powder



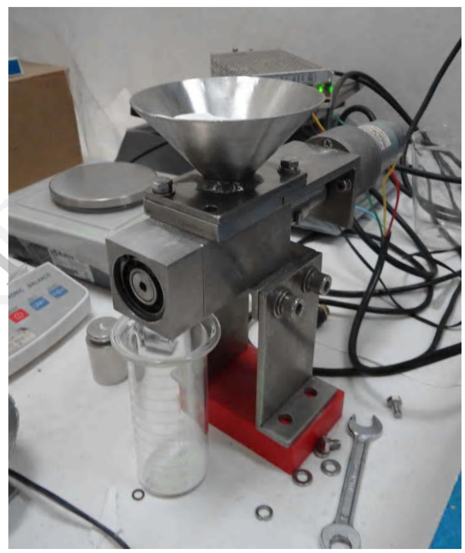

Fig.11. Powder dispenser in operation

Fig. 12. View of flow of the powder through hopper when the dispenser is in operation

Fig.13. VDCSFPD with stirrer in operation during experiment with inactive Zr-Mo powder

Figures 5 to 13 show the experimental set-up involving the hoppers used, the powder dispenser and the powder dispenser with stirrer. Time was noted using the stop watch and the mass of the powder was measured using the calibrated electronic balance. Volume was measured using the volumetric beaker specially fabricated for experiment purpose. Experiment performed by passing the powder through the hoppers having different angle $\varphi_s$ and through the existing dispenser with stirrer in the hopper. The bulk density of the powder was checked before passing the powder through the dispenser. Experiments performed by fabricating the hopper having $\varphi_s$ angle upto 63º only as it was observed that after $\varphi_s = 47º$, the flow rate of Zr-Mo powder gets stabilized.

### 2.C Results of experiment to select the most appropriate $\varphi_s$ angle

From the data related to the flow rate of the powder through the dispenser it is found that the flow rate exhibited by the dispenser remains constant after the hopper angle $\varphi_s = 47º$ and more. Table-1 shows the data about the flow rate and the figure 14 the graphs showing the characteristic curve of flow rate against the hopper angle $\varphi_s$. On comparison with the corresponding flow rate through the existing machine, it is found that the flow rate increases by 1.8 to 2 times for $\varphi_s = 47º$ and more thus achieving the objective of increasing the flow rate.

### 2.D. Interpretation of the result of experimentation

The objective of selecting a most appropriate $\varphi_s$ angle and increase the flow rate through the powder dispenser attained. As far as the result of the experiment is concern, the trend observed that the flow rate from the dispenser remains constant after a certain value of $\varphi_s$. It may be due to the flow rate of powder through the hopper getting equal to or more than the flow rate induced by the screw feeder. Flow rate through the screw feeder is controlled by the screw RPM and geometry of the screw etc. In case of VDCSFPD with stirrer, the flow rate is controlled by the stirrer and therefore the dispensing rate of this powder dispenser is less than the powder dispenser without stirrer. During experiment, it was found that in case of $\varphi_s$ below 50º , the powder remained stick to the wall of the hopper even after full delivery from it. Therefore, hopper angle $\varphi_s = 50º$ has been selected.

### II.E Characterization of VDCSFPD fitted with a hopper having $\varphi_s$ of 50º

With the objective of the removing the stirrer and to increase the flow rate of the dispenser, experiment was performed to finalize the $\varphi_s = 50º$ angle. In order to implement this improvement in the design of the existing machine, it was decided to fabricate the hopper for 500g mass of the powder. Hopper with stirrer of the powder dispenser was removed replaced with the 50º hopper. For ease of the operator during production operation, plotting a characteristic curve helps in better understanding of the machine.

Table 1 : Flow rate through powder dispenser fitted with hopper with stirrer and the hopper having various angle $\varphi_s$ without stirrer

| Sr No. | Sample powder bulk density in g/CC | Flow rate gm/sec | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VDCSF-PD Hopper with stirrer | Proposed hopper slope angles in degree | | | | | | | | | |
| | | | 36 | 38 | 40 | 41 | 44 | 47 | 51 | 55 | 56 | 63 |
| 1 | 1.32 | 0.22 | 0.37 | 0.39 | 0.4 | 0.407 | 0.415 | 0.41 | 0.402 | 0.402 | 0.4 | 0.4 |
| 2 | 1.4 | 0.18 | 0.468 | 0.485 | 0.459 | 0.453 | 0.402 | 0.402 | 0.402 | 0.395 | 0.395 | 0.395 |
| 3 | 1.355 | 0.231 | 0.398 | 0.406 | 0.423 | 0.429 | 0.442 | 0.448 | 0.448 | 0.448 | 0.451 | 0.452 |



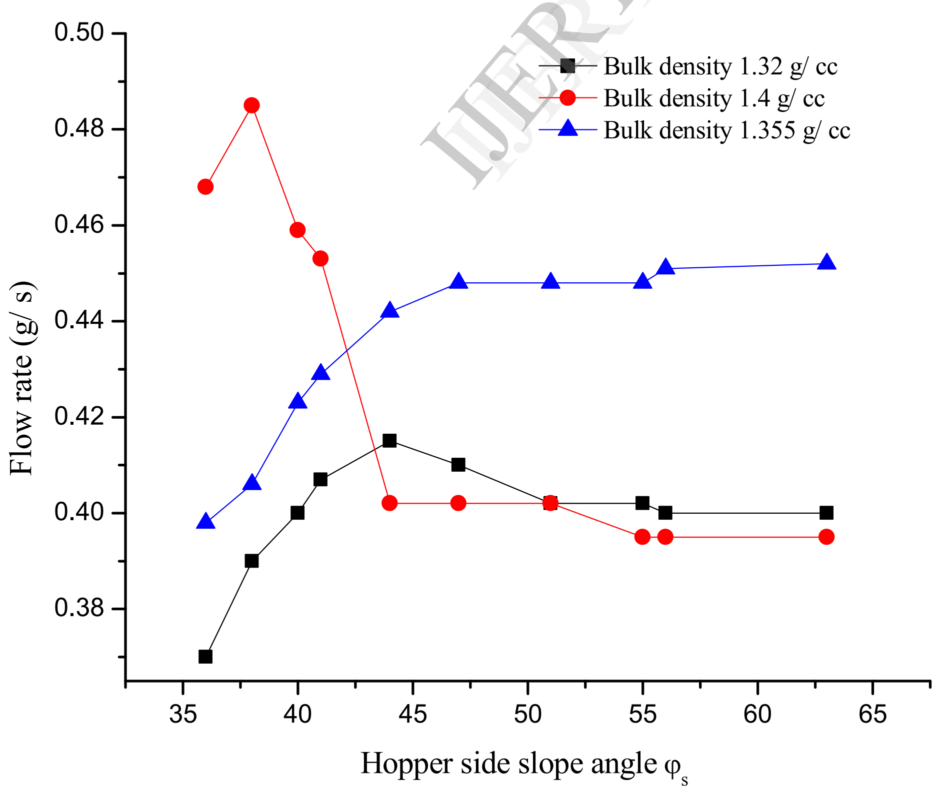


Fig.14 The graph of flow rate vs hopper angle $\varphi_s$

Table 2: Flow rate of the VDCSFPD fitted with hopper having $\varphi_s = 50^o$

| Sr. No. | Sample powder bulk density | Flow rate in g/sec |
|---|---|---|
| 1 | 1.334 | 0.264 |
| 2 | 1.604 | 0.301 |
| 3 | 1.202 | 0.33 |
| 4 | 1.29 | 0.322 |
| 5 | 1.245 | 0.303 |
| 6 | 1.48 | 0.306 |
| 7. | 1.525 | 0.33 |
| 8 | 1.-08 | 0.255 |
| 9 | 1.199 | 0.282 |
| 10 | 1.25 | 0.305 |

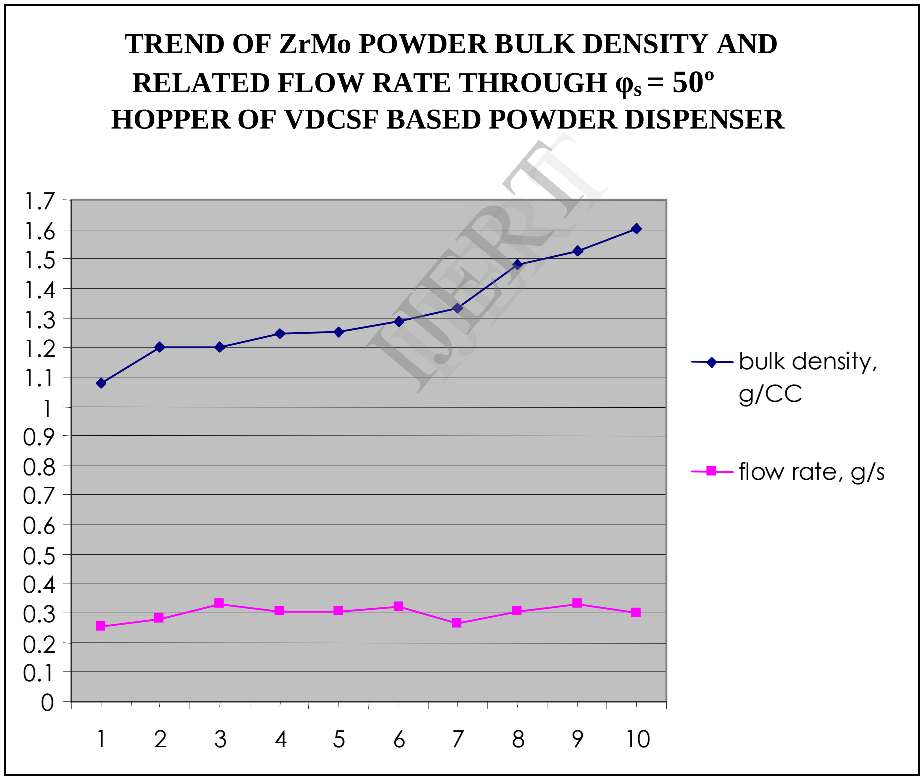


Fig. 15 Flow rate through VDCSFPD with hopper having $\varphi_s = 50^o$

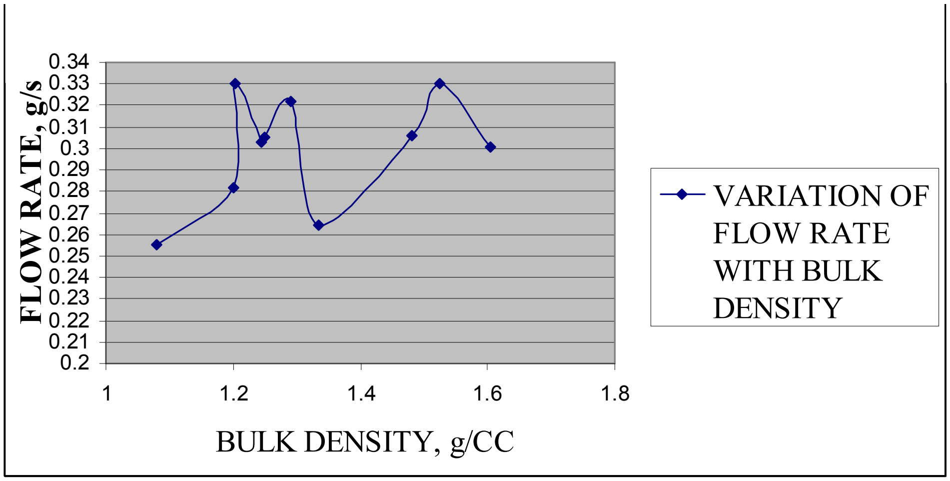


Fig. 16 Flow rate through the VDCSFPD fitted with hopper having $\varphi_s = 50^o$

Accordingly, study of the machine was done using the inactive Zr-Mo powder with different bulk densities. In this study, mass was measured using the electronic balance and volume using the volumetric beaker. By using the electronic timer, time to dispense fix mass of powder by the powder dispenser was noted. In all total 10 inactive samples were tested and the flow rate is tabulated (see table-2). Characteristic curve is plotted (see fig. 15 and 16). From fig.14, inference can be drawn that irrespective of the bulk density, the flow rate through the dispenser is 0.3g/s. In fig.16, the variation of the flow rate through the dispenser fails to give any trend and so the curve in fig.14 can give the better idea about the powder dispenser.

## 2.F Conclusion

By using the methodology of experiments, design and fabrication of the hopper having 50º hopper side slope angle has been selected over the hopper with stirrer. Selection was based on the factors like maximum flow rate through the established screw feeder, minimum retention of the powder in the hopper. Further, characterization of screw feeder with the 50º hopper was done by experimentation only and it has been found that irrespective of the powder bulk density, the flow rate remains constant ~0.3g/s.

## 2.G. Acknowledgments

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