Numerical Modelling and Mathematical Modelling of Non-Contact Gripper for Maximum Negative Pressure and Grasping Area

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Abstract - The aim of this paper is to provide a mathematical relationship between the geometrical parameter (cone radius), input parameter (volumetric flow rate) and constraint condition (gap height) with the grasping parameters for non-contact gripper. The cone mill Bernoulli gripper is taken as the reference model. The grasping parameters are negative pressure and grasping area. Thus, to provide the mathematical relation four different cone radius, three volumetric flow rates and three gap heights are taken. With the help of statistical tool (MINITAB) the mathematical relationship is established. A standard full factorial design is chosen to provide the regression equation. With the help of interaction graph the effect of individual parameters on grasping are established.

***Key Words*:** *Non-contact gripper, Bernoulli, Automation, Grasping area, Negative pressure, Face Radius (FR).*

I.INTRODUCTION

In recent years, robotics in food industries got momentum and a large number of researches have been carried out. Researchers continue to design new robots and grippers with greater capabilities to perform more challenging and comprehensive tasks. The food market has been rapid growth in recent years. Current consumer trends reflect the increasing popularity of ready meals that maybe quickly and simply prepared. The industrial manufacture of ready meals could be a high-volume method that has comparatively low profit margins as a result of the complexness of the product and high levels of competition between food market chains. As the demand for convenience food continues to rise, manufacturers are searching ways in how to extend their production capability while at the same time reducing production prices. Thus, Bernoulli gripper gains importance, it used the atmospheric air as a medium to lift the object. Several authors have proposed many designs such as Rawal et al. (2008) have developed rectangular cross section gripper which is of a non-contact type for bakery industries to handle biscuits. The need for non-contact gripper is to avoid contamination. The author used the radial flow nozzle to obtain the smooth flow. In case of Rosidah Sam &SamiaNefti (2010), Rosidah Sam &NorlidaBuniyamin (2012) they had conducted an experiment with round shape, flat shape, and irregular shape food products. They concluded that the range of weight for round object reduced drastically compared with flat and irregular shapes. The reason behind the weight reduction is the surface smoothness of the circular object. They have justified by experiment that the "ability to lift decreases with increase in surface smoothness" and for the irregular shape of food, the gripper needs higher air flow rate than the flat type food. Matthew et al. (2011) had suggested a Bernoulli gripper with pintle**.** The gripper uses deflector plate in the face region which looks like a concave nozzle. This gripper is used for handling large plates and the face can be expanded as required.

II.DESIGN EVOLUTION

The cone mill Bernoulli gripper is chosen to overcome the limitation of conventional gripper. It avoids the direct impingement of air to the object. The figure 2.1 shows the air flow path of cone mill gripper. The air enters the stem and it get deflected by the cone mill and it hits the objects in a specified angle. The cone mill gripper can't mask the work piece fully from air, it just avoids direct impingement by deflecting in to some angle.

In cone mill design, apart from the advantages it has limitation of producing negative pressure only with in the centre, which is equal to the diameter of the cone. As the diameter of the cone is small the grasping area is small. Lifting of non-rigid object by small surface area on its surface cause damage to the object. To overcome the limitation, the grasping area should cover maximum surface area of the object. For that the cone mill is to be designed in such a manner to distribute the negative pressure throughout the surface of object. The optimum value of the cone mill radius is to be found by experimenting it with different cone radius. To find the effect of cone radius on other factor such as flow and gap height. The parameter of flow and gap height is also considered.

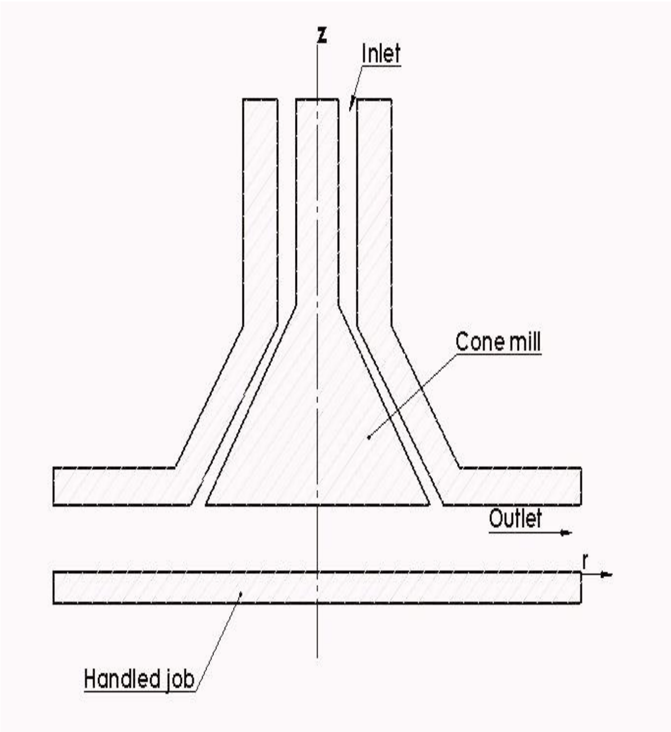


Figure 2.1 Cross section of cone mill gripper

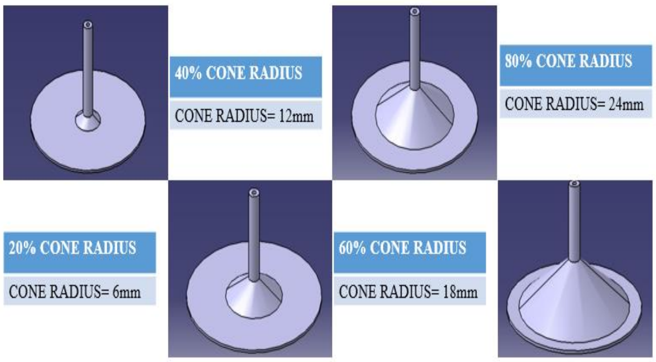


Figure 2.2 3D model of gripper A/F path

The cone mill radius is varied as 20%, 40%, 60% & 80% of face radius. The cone mill angle is set as 30 degrees, which is said as optimum by Dini et al-2009. So, the cone mill radius is varied without altering the cone angle. The specification of gripper is shown in table 2.1.

Table 2.1 Specification of gripper

Specification	Dimension
Inner radius (r_1)	1mm
Outer radius (r_2)	2.5mm
Cone angle	30° and 35°
Outer face radius (R)	30mm
Cone radius	6,12,18,24 mm

III.DESIGN OF EXPERIMENTS AND COMPUTATIONAL FLUID DYNAMICS

The factors that are considered for DoE are the cone radius, flow and gap height. As already discussed in design evolution, four level is taken for coneradius. Three level is chosen for gap height and volumetric flow rate. The factors and their levels are shown in the table 3.1.

Table 3.1 Factors and their level

FACTOR	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
CONE RADIUS	6mm	12mm	18mm	24mm
FLOW	15 L/min	20 L/min	25 L/min	-
GAP HEIGHT	1mm	1.5mm	2mm	-

A full factorial design may also be called a fully crossed design. So to study the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable the full factorial design is chosen. As the no of factors and levels are known, the total no of experiments can be calculated 4 X 3 X 3 = 36. The 36 experiments are to be carried out in a random order given by the full factorial design.

The three phases of CFD is carried out. In the pre-processor stage the geometry is defined, the discretization of geometry done and the boundary condition are defined and it is shown in the table 3.2. The k-ε model is choosed for the simulation. The solution is carried out in solver phase. The results are taken in the form of contour plot and pressure plot in post processing phase. The pressure plot and contour plot for 12 stimulations are shown in the figure 3.1 and 3.2.

Table 3.2 Boundary condition

Boundary type	Value
volumetric flow rate	• volumetric flow rate: 15 l/min, 20 l/min, 25 l/min • Temperature: 300 K
Pressure outlet	Gauge pressure: 0 Pa
Wall	Standard wall
Bottom	Standard wall

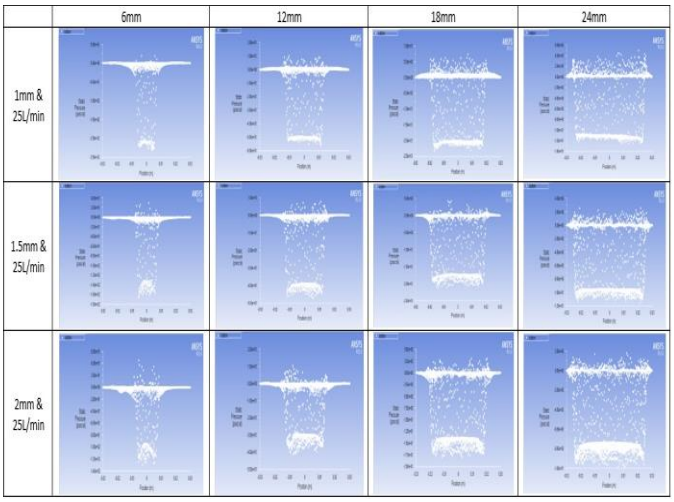


Figure 3.1 Pressure plot

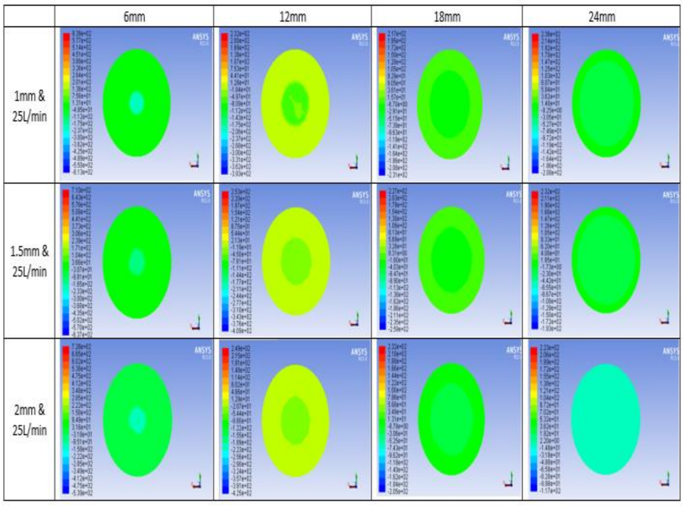


Figure 3.1 Contour plot

From this pressure plot and contour plot the maximum negative pressure and grasping area is found. The sketch and calc. software is used to find the grasping area. The sketch and calc. is an area calculator which is used to find the area of irregular surface area.

IV.MATHEMATICAL MODELLING

The results of computational fluid dynamics are taken as input to generate regression equation for maximum negative pressure(MNP). The anova table is generated by taking the flow, gap height and cone radius as factors, maximum negative pressure as response. The interaction terms are considered to find their contributions of it over the response. The anova table is shown in the table 4.1 and the residual plot is shown in the figure 4.1.

Table 4.1 Anova table for maximum negative pressure

SOURCE	DF	Adj SS	Adj MS	F-Value	P-Value
Cone Radius	3	82301	27433.7	186.04	0.000
Flow	2	12895	6447.4	43.72	0.000
Gap Height	2	3171	1585.3	10.75	0.002
Cone Radius * Flow	6	8237	1372.9	9.31	0.001
Cone Radius * Gap Height	6	5587	931.2	6.31	0.003

Flow * Gap Height	4	816	204	1.38	0.297
Error	12	1770	147.5	-	-
Total	35	114777	-	-	-
MODAL SUMMARY					
S	R-sq	R-sq (adi)	R-sq(pred)		
12.1435	98.46%	95.50%	86.12%		

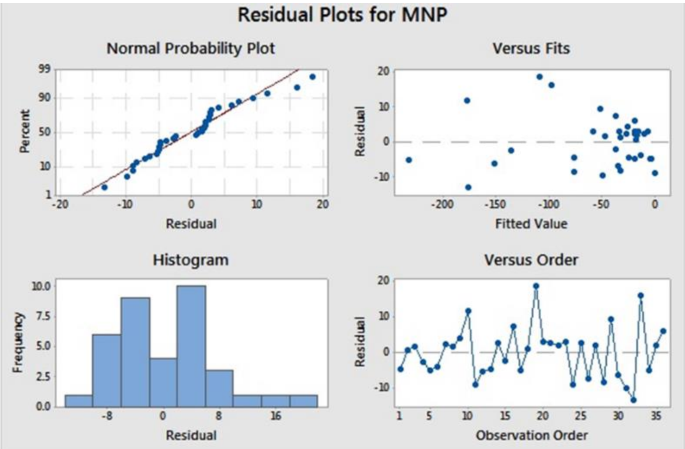


Figure 4.1 Residual Plot for maximum negative pressure

The regression equation for maximum grasping area also found in the same manner the anova table and residual plot for the maximum grasping area is shown in table 4.2 and figure 4.2.

Table 4.2 Anova table for maximum grasping area

SOURCE	DF	Adj SS	Adj MS	F-Value	P-Value
Cone Radius	3	21935039	7311680	4308.7	0.000
Gap Height	2	466079	233039	137.33	0.000
Flow	2	378	189	0.11	0.895
Cone Radius * Gap Height	6	1215119	202520	119.34	0.000
Cone Radius * Flow	6	7742	1290	0.76	0.614
Gap Height * Flow	4	9431	2358	1.39	0.296
Error	12	20364	1697		
Total	35	23654151			
MODEL SUMMARY					
S	R-sq	R-sq (adj)	R-sq (pred)		
41.1942	99.91%	99.75%	99.23%		

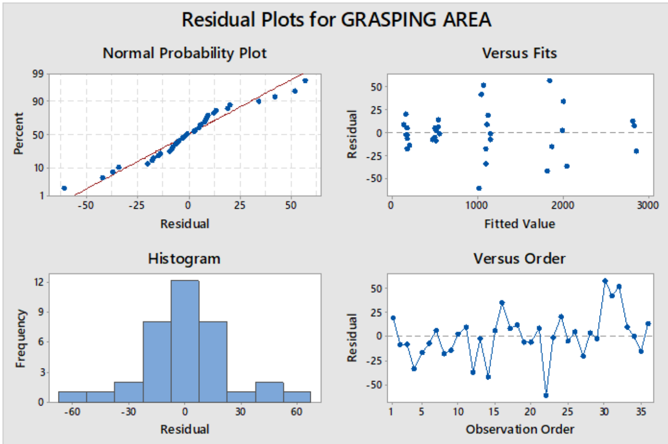


Figure 4.2 Residual Plot for maximum grasping area

The regression equation for maximum negative pressure **(MNP)** and maximum grasping area is given in the equation 4.1 and 4.2.

MNP = -90 + 19.53 cone radius - 14.5 flow + 61.3 gap height - 0.5949 cone radius * cone radius - 0.012 flow * flow - 9.0 gap height * gap height + 0.488 cone radius * flow -3.43 cone radius* gap height + 2.00 flow*gap height **Equation- 4.1**

Grasping Area = 1523 - 124.7 cone radius - 1358 gap height + 10.3 flow + 5.455 cone radius * cone radius + 289 gap height * gap height - 0.25 flow * flow + 50.05 cone radius * gap height - 0.075 cone radius * flow + 0.3 gap height * flow

Equation- 4.2

V.RESULTS AND DISCUSSION

The regression equation is reduced in the manner to have only significant terms. The equations are shown in equation 5.1 and 5.2.

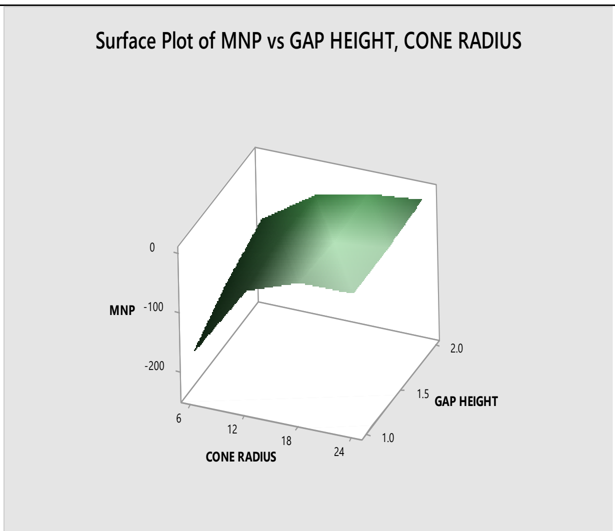
MNP = -90+ 19.53 cone radius -0.5949 cone radius * cone radius + 0.488 cone radius * flow - 3.43 cone radius* gap height

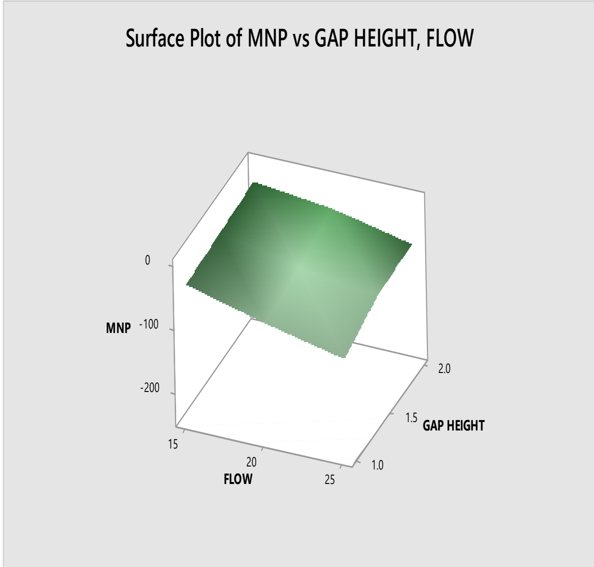
Equation- 5.1

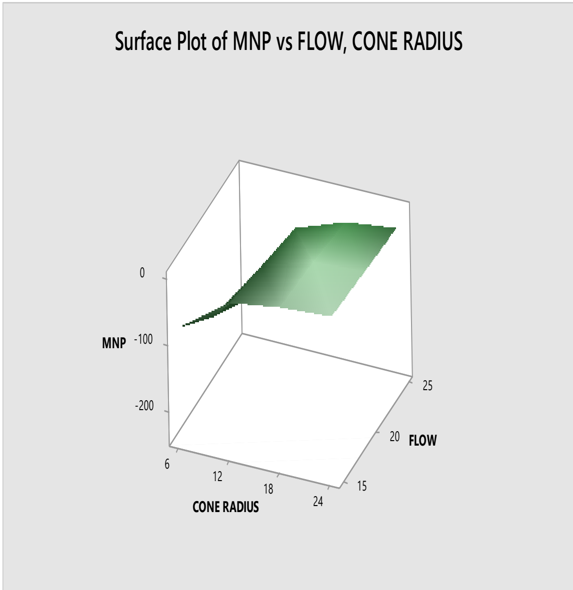
Grasping Area = 1523 - 124.7 cone radius + 5.455 cone radius * cone radius + 50.05 cone radius* gap height **Equation- 5.2**

Table 5.1 Effect of Interaction term on their Response

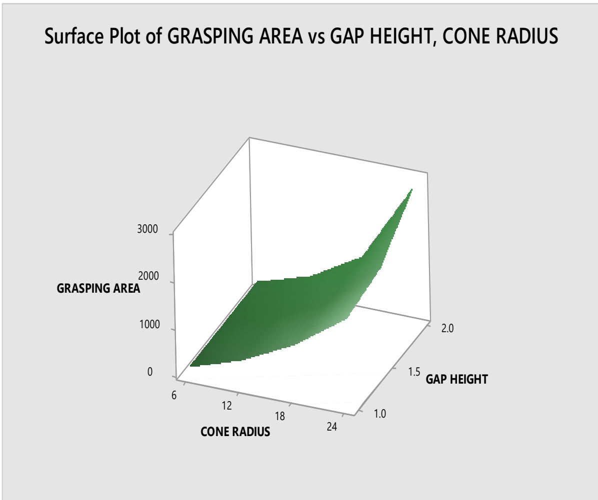
Maximum Negative Pressure (MNP)







Grasping Area



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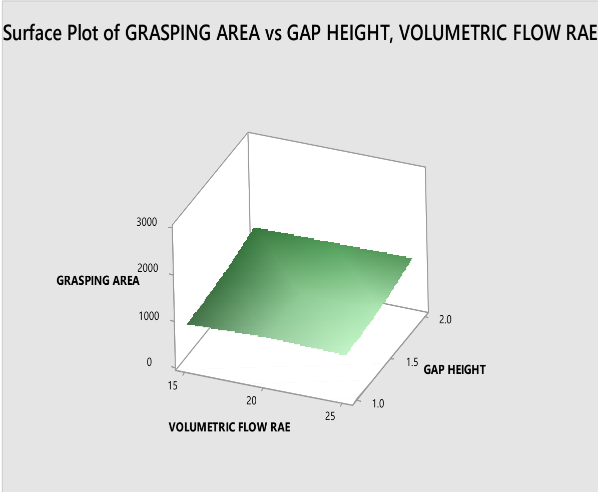
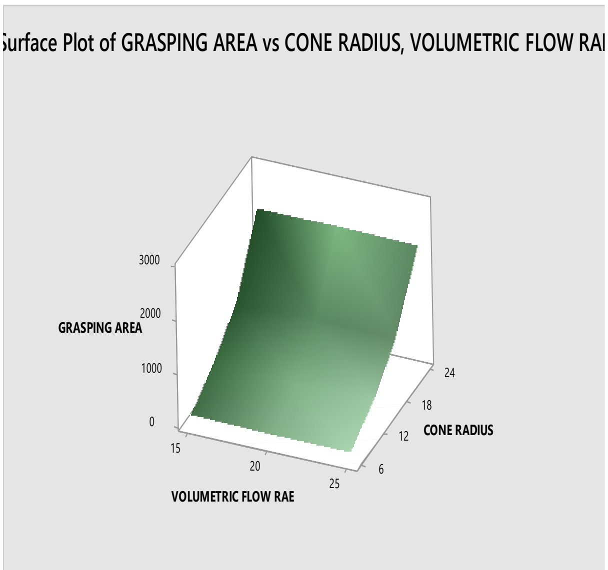
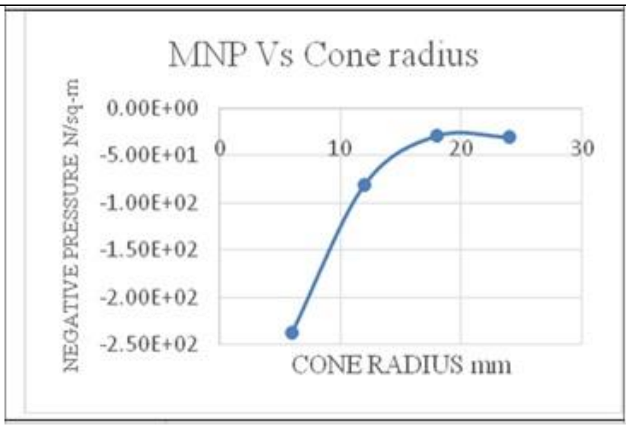




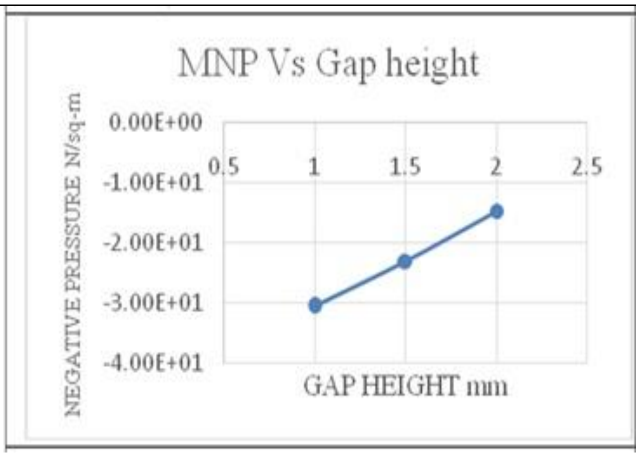
The effect of interaction terms is shown in the form of graph in table 5.1. By interpreting the graph, it is evident that the flow rate and the gap height vs response graph is flat, which shows there is no significant change on their responses. The cone radius and gap height vs response graph shows more variation in cone radius axis than gap height. The flow and cone radius vs response graph shows more variation in cone radius axis than flow in terms of maximum negative pressure. In terms of grasping area, the flow is linear with respect to various cone radius. It shows it has no effect on the grasping area.

Table 5.2 Effect of individual factors on their Response

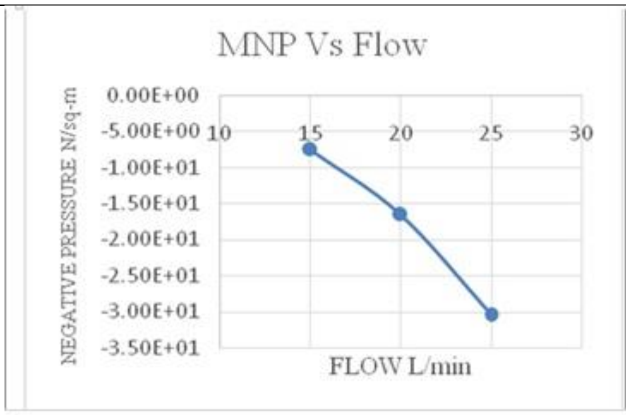
Maximum Negative Pressure (MNP)
Gap height 1 mm and Flow 25 L/min



Cone radius 24 mm and Flow 25 L/min

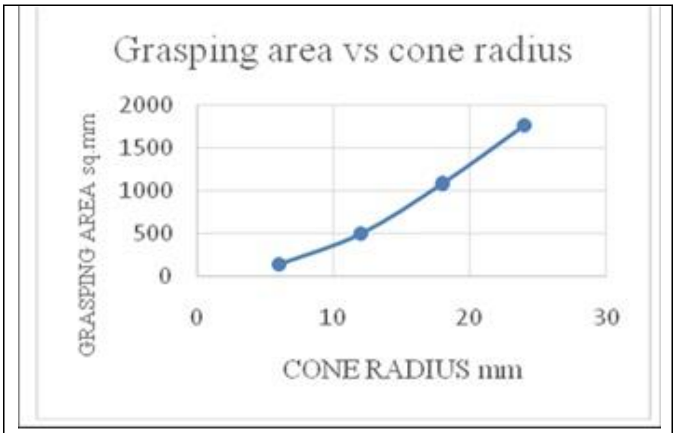


Cone radius 24 mm and Gap height 1 mm

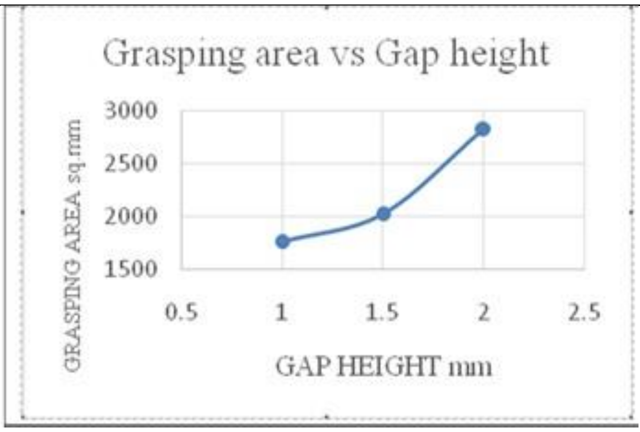


Grasping Area

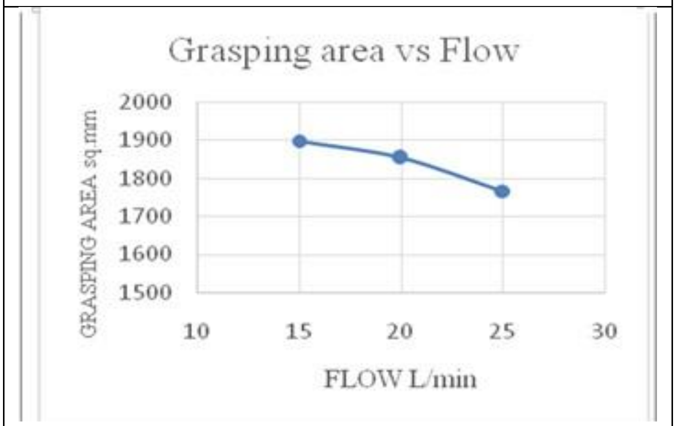
Gap height 1 mm and Flow 25 L/min



Cone radius 24 mm and Flow 25 L/min



Cone radius 24 mm and Gap height 1 mm



The table 5.2 gives the effect of individual factors on the responses, unlike the above interaction graph it is drawn by only with the help of few values. The negative pressure intensity decreases with increasing cone radius. In the above graph at 18mm and 24 mm it is nearly same. By considering the other values of gap height and flow, it is concluded as said above. In terms of grasping area, it increases with increase in cone radius.

When the gap height increases the intensity of negative pressure get decreased and the grasping area value get increased. In the case of volumetric flow rate, the intensity of negative pressure increases with increase in flow rate. In the above graph, it is shown that the grasping area decreases with increase in flow rate. But by considering other values of gap height and cone radius the trend of the graph changes. Except for the 24-mm cone radius and 1mm gap height the grasping area increases with increase in flow rate. By considering all the three factors in terms of grasping area, the flow rate is not significant. The changes in area lies within 100 sq-mm. It is small when compared to other two factors. By considering all these it can be conclude that the grasping area has no effect by change in flow rate.

VI.CONCLUSION

Thus, the mathematical relation between the geometrical parameter (cone radius), input parameter (volumetric flow rate) and constraint condition (gap height) with the grasping parameters is established. The individual effect of factors on grasping parameters is, the negative pressure intensity decreases with increase in cone radius and with increase in gap height. But in case of volumetric flow rate it is vice versa of other two factors. The negative pressure intensity increases with increase in volumetric flow rate. In terms of grasping area, it increases with increase in cone radius and increase in gap height. The volumetric flow rate has no significant effect as other two factors.

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