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RESEARCH ARTICLE

FABRICATION OF MICROWAVE POPCORN BAG.

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Abstract

Microwave popcorn bags are industrial oriented product which is being in use in our day today life. Available microwave popcorn bag are performing well in terms of storage and maintaining flavour of food material kept inside them. But these have some serious disadvantages which causes severe health related problems. Their existing manufacturing technology is very costly. So there is great need to find out novel ways to manufacture these bags so that they can be manufactured at lower cost with no health harms.

We have tried an attempt to do so, by replacing Aluminum foil used in modern microwave popcorn bags with 10% PVA solution's coating. We have found that when this coating is done on outer side of envelope then it gives best results in terms of cooking efficiency. We have also find out that optimized cooking time for food material inside such bags is, 3 minutes. Use of PVA solution will definitely reduced cost of manufacturing of these microwave popcorn bags. PVA is not health hazardous and it is currently being used in various food items such as in manufacturing of chewing gum. Use of PVA also eliminates the risk of cancer which was major problem in long term use.

Introduction:-

Microwave Popcorn Bag (MPB) are basically the bags typically containing solidified cooking oil, one or more seasonings (often salt), and natural or artificial flavourings or both. The bag is typically partially folded when it is placed in a microwave, and inflates as a result of steam pressure from the heated kernels. **Microwave Popcorn Bag (MPB)** is made up of Kraft Paper coated with plastic film. There is usually a plastic coating **[PET (Polyethylene Terephthalate)]** on the inside of the paper that makes up the bag. This prevents the oil from soaking into the bag when it is heated and becomes liquid. It also have **PFOA (Perfluoro-octanoic acid)**, also called as C-8. PFOA is chemical which joins non stick coating to paper.[16]

Packaging of MPB is done in a special way, means it has special dimensions to bear force generated by popping of popcorn kernels. In MPB, the maize kernels rest on top of the **susceptor** (Metal film in MPB), in a solid cake of oil and flavourings. Oil used must be solid at room temperature and oil that is solid at room temperature is either very high in saturated fats or partially hydrogenated (Trans fat). Saturated fat has strong connections to heart disease and many cancers. So it is a disadvantage of MPB.

The design of a microwave popcorn bag is specifically keyed to avoid popped kernel scorching, an undesirable effect that takes place when popped kernels are heated **above 300 °F (149 °C)**.[1] For this, usually a metalized film

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called as **Susceptor**, which is laminated onto the paper of the bag which absorbs microwaves and concentrates heat at the film interface which in turn ensuring a even heat distribution & even flavour distribution throughout the product. It absorbs microwaves and converts them into heat, lots of heat. The susceptor can get much hotter and that helps in reduction of the number of dud kernels. The susceptor gets so hot that it releases the chemical which is then absorbed by the oil that coats the popcorn. The chemical is a known **carcinogen**. It is a serious disadvantage of MPB.

Inner lining of bag contains non stick chemical such as **Diacetyl**, which are transferred to popcorn we eat. Diacetyl gives buttery and cream taste to snack and it occurs naturally in various products such as dairy products, coffee etc. Diacetyl has a lot of disadvantages in terms of health issues.[11] It causes various diseases such as liver cancer, testicular cancer, pancreatic cancer, infertility in women, necrosis of nasal epithelium and inflammation at nasal level.[12,13] It also prevents childhood vaccination to work properly. Due to these reasons various companies have limited use of Diacetyl. Beside Diacetyl MPB have other issues also. When bag is opened certain chemicals are originated such as, Chemicals originating from the ink or glues on the bag e.g. **p-Xylene**, Chemicals from popcorn flavouring e.g. **Diacetyl** and **Perfluorinated alcohol** (in some cases only) from perfluoronated coating on bag.[2] Susceptor becomes heated and heat is generated. This heat causes the oil present in MPB, to bubble. Heat also causes scorching of MPB. Both of these conditions can be easily seen in above figure. Susceptor has an important role to play in MPB but it has many disadvantages too. It produces enormous heat but that heat is itself disadvantageous. Heat causes the plastic and metal to burn of & now they can release to popcorn kernel (food item, which we are going to eat). By now we have come to know that MPB has many limitations and those can be fatal for our health also, so there is strict requirement for its modification and it can be modified by making use of **10% PVA (Polyvinyl alcohol) coating on Kraft paper**. Properties of PVA, which make it a suitable choice for this purpose, are as following:-

1. **Have film forming properties**: - So it can be easily used for coating on paper.
2. **Have adhesive properties**: - It will easily and strongly bind with paper.
3. **Have resistant properties to oil & grease**: - It is also desirable property because we will never want that oil and other flavours would leak from the paper.
4. **Most important, it is non-toxic**:-[9,10] PVA is non toxic so it can be used for coating of paper which is going to be used in food packaging.
5. **Have high melting point**: - So scorching of popcorn bag will not be there.
6. **It can be used as paper coating**: - PVA is used in paper coating but along with pigments such as clay in present time. So, there is no doubt that it can be used for paper coating.
7. **It can absorb microwaves of 2.45 GHz frequency**:-[4,5] It is the most important property of PVA because, 2.45 GHz frequency range used in Microwave oven for cooking purpose. Hence it can be warmed in microwave oven.

Polyvinyl alcohol may be a good substitute of metal film in microwave popcorn bag. Most importantly PVA is able to work properly in microwave oven.[3] Microwave heats any substance via a special mechanism called as **Dielectric Heating** and PVA have such properties.[6,7,8] Dielectric heating it is also called as **electric heating** & it is caused by **molecular dipole rotation**. In dielectric heating molecular rotation occur in material containing polar molecules and they align themselves in an electromagnetic field. Rotating molecules push, pull & collide with other molecule & distributes energy to adjacent molecule. Agitation of molecules occurs and it increases the temperature of material. In above figure the thin black arrow indicates the direction of the dipole of adsorbed polar molecule, while the thick blue arrow shows the local electric field. Polyvinyl alcohol has polar groups which show vibration and rotation in microwave field so PVA can be used.

Various experiments were performed, and following consolidating results were obtained which proves that PVA is a good alternative of metal film in MPB.

1. **10% PVA coating produces best results among 5% and 15% PVA solution.**
2. **Outer side coating is useful.**
3. **Optimized time for cooking is 3 minutes.**
4. **Unsized, unbleached brown Kraft paper is best for making popcorn bag at lower cost**.

Materials and methods:-

Preparation of PVA Solution can be understood with the help of an easy example. Let, we want to prepare 10% PVA solution in volume of 10 ml then the procedure would be as following:-

Which type of PVA coating is best- one sided or two sided?

Methodology for experiment-

Our first aim was to check weather food material kept in an envelope or bag prepared by a Kraft paper coated with PVA solution is able to cook food kept inside or not. For this we followed following steps:

a. We took 3 handmade paper sheets.
b. We prepared an envelope from uncoated sheet and kept 8 uncooked maize kernels into it.
c. We took another sheet and coated it on both sides with 10% PVA solution, and then kept 8 kernels into it also.
d. We took another paper and coated only one side of it and prepared an envelope such that coated side was opposite to kernels means we used outer coating. This envelope also contained 8 kernels.
e. After preparing these three envelopes we kept all these in microwave oven, one by one for 2 mins at 100 degree Celsius.
f. After cooking, we observed results in terms of Popping Efficiency (Cooking Efficiency) for each paper.

How porosity plays an important role in thermal heating & cooking of food material in microwave oven;-

1. **Venue**- CPPRI (Central Pulp & Paper Research Institute).
2. **Apparatus used-**
   - **a. Microwave Oven-**
     - **(i) Company Name-** LG Pvt. Ltd.
     - **(ii) Model-** Bar be Cook Grill, MG-607 APR
   - **b. Coater-** ZEHNTNER ZAA 2300
   - **c. Coater rod with grooves of 182 microns depth**
   - **d. Paper sheets**
     - **(i) MG Paper (Machine Glazed Paper) -** It has one side smoother and second side rough. It has less porosity as compared to handmade paper sheets. It is very thick also.
     - **(ii) Cream Wove Paper**- It is thin paper and it is more porous than MG paper. It has no chemicals.
   - **e. Solution for coating-** 5% and 15% PVA solution, which was prepared on day 3.
   - **f. Popcorn kernels from** ACT-II Popcorns, Con Agra foods.
   - **g. Weighing machine.**
3. **Conditions used-**
   - **a. Temperature of microwave oven** = 100 degree Celsius
   - **b. Frequency of microwave oven** = 2.45 GHz
   - **c. Time for cooking popcorn kernels** = 3 mins
4. **Methodology for Experiment-**

From the knowledge of 2nd day experiment at CPPRI, we concentrated only on one sided coating with more parameters and measurements. We performed experiment in following steps-

a. First we took MG paper and made 2 envelopes from this. One was containing inner coating while other was having outer coating of both 5% and 15% PVA solution separately.
b. We weighed each paper before coating and after coating and this were helpful in knowing exact amount of coated PVA amount.
c. After this we kept 8 kernels in each envelope and and observed Popping efficiency of each bag along with uncoated envelope, which was used as a blank sample.
d. Same procedure was applied onto Cream Wove Paper.

Finding best PVA solution's concentration among 5%, 10% and 15% PVA solution:-

By now we know that porosity of paper has important role in thermal conductivity of paper. Air is bad conductor of heat and the paper which is more porous means having more air in its void spaces. Cream wove paper was more porous while MG paper was of lesser porosity. That is the reason that cream wove paper gave poor cooking efficiency without coating but MG paper gave good results without coating.

Now, the question was, among the 5%, 10% and 15% concentration of PVA solution which concentration is best? To know this we performed cooking experiment again. Details of experiment performed are as following

1. **Venue**- CPPRI (Central Pulp & Paper Research Institute).
2. **Apparatus used-**
   a. **Microwave Oven-**
   (i) **Company Name-** LG Pvt. Ltd.
   (ii) **Model-** Bar be Cook Grill, MG-607 APR
   b. **Coater-** ZEHNTNER ZAA 2300
   c. **Coater rod with grooves of 182 microns depth**
   d. **Paper sheets:-Cream Wove Paper**- It is thin paper and it is more porous.
   e. **Solution for coating-** 5%, 10% and 15% PVA solution
   f. **Popcorn kernels from** ACT-II Popcorns, Con Agra foods.
   g. **Conditions used-**
   (i) **Temperature of microwave oven** = 100 degree Celsius
   (ii) **Frequency of microwave oven** = 2.45 GHz
   (iii) **Time for cooking popcorn kernels** = 3 mins
3. **Methodology of Experiment:-**
   a. We took 6 cream wove papers.
   b. We coated 2 papers with 5% PVA, 2 papers with 10% PVA and remaining two papers with 15% PVA solutions.
   c. We prepared 6 envelopes from these 6 papers.
   d. We kept 8 popcorn kernels in each of the envelope.
   e. Each envelope was kept in microwave for 3 minutes at 100 degree Celsius.
   f. After cooking efficiency of each bag was calculated separately.

Finding optimized time of cooking for microwave popcorn bag:-
Methodology used was as following:-

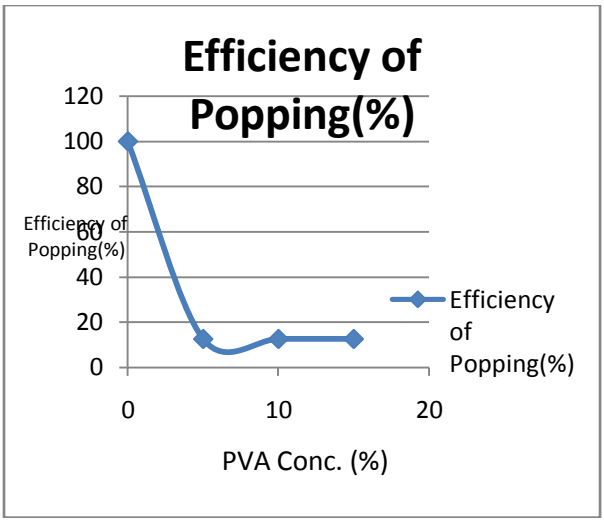
a. We took 4 envelopes which were outer sided coated with 10% PVA solution. Those envelopes were made from Kraft paper.
b. Now we kept 8 kernels in each of the envelope.
c. We kept all the 4 envelopes in microwave oven for various time periods such as for 3 minutes, 4 minutes, 5 minutes and 6 minutes.
d. We noted down cooking efficiency of each envelope.

Results and Discussion:-

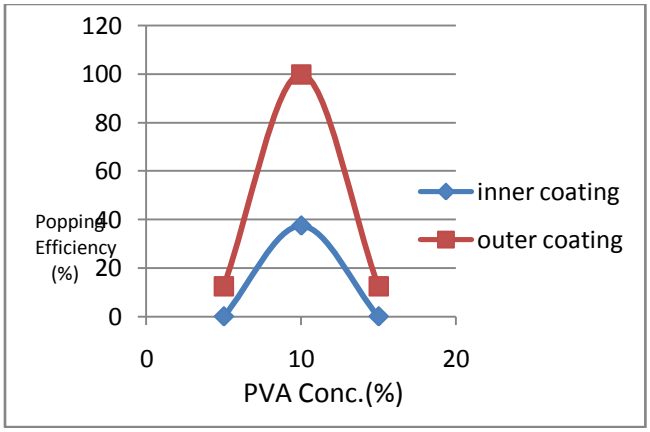
We tried to find out that that how cooking efficiency of different bags changes without coating, one sided coating to two sided coating. Results of experiment performed are as following.

Conclusion from above Results:-

Two sided coating of PVA solution didn't produce encouraging results, which shows that one sided coating of PVA solution can produce much better desirable results.



Graph 1:- Popping efficiency of MG paper at different conc. of PVA solution



Graph 2:- Comparison of inner and outer coating in terms of Popping Efficiency

Conclusion after performing above experimental work:-

1. One sided coating is beneficial.
2. Outer coating is useful.
3. Porosity of paper has important role in thermal heating & cooking of food material in microwave oven.

Our next aim was to find out the best concentration among 5%, 10% and 15% PVA solution. For finding this experiments were performed and following results were obtained:-

Results:-

Now it is also important to find out the optimized cooking time for the MPB prepared by us.Experiments were done and following results were obtained.

Table 3:- Finding optimized cooking time for popping of popcorn kernels

Conclusion:-

Optimized Time for cooking is 3 minutes.

We have replaced Aluminum foil used in Microwave Popcorn Bag, (which is being used for producing heat, necessary for popping of popcorn present inside bag) with PVA coating. Conclusion till now, are as following:-

1. **10% PVA coating produces best results among 5%, 10% & 15% PVA solution.**
2. **Outer side coating is useful.**
3. **Optimized time for cooking is 3 minutes.**

Coating on Kraft paper was done with different-2 concentrations of PVA & Coated paper were produced, which were having single sided as well as double sided coating. Envelopes were prepared from those coated papers. Maize kernels were taken in those envelopes and then Envelopes were kept inside Microwave Oven. Popped Popcorns were ready to eat. All these lead to above conclusions.

Theoretical explanation of queries generated from above mentioned conclusions:-

Q. 1 Why PVA Coating is producing heating effect?

Ans- PVA is having polar group (OH).

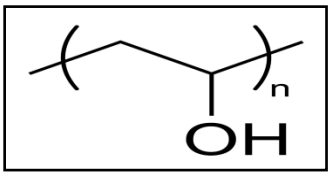


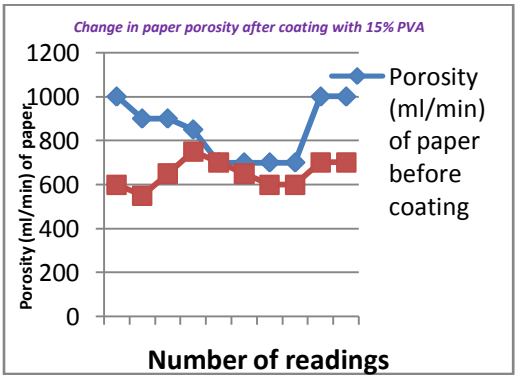
Fig 10: Structure of PVA miolecule

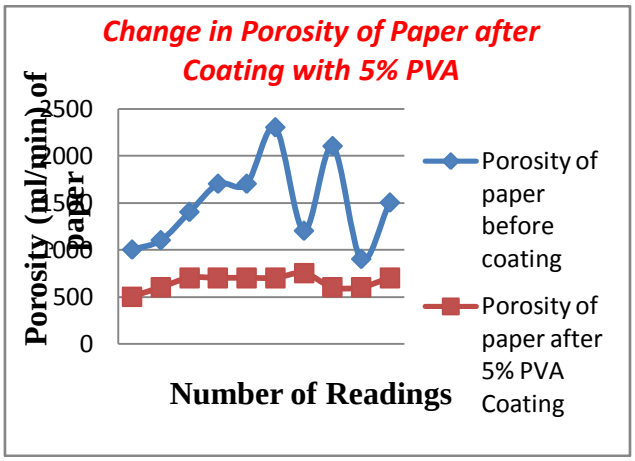
Those polar molecules are getting excited on absorbing Electromagnetic (EM) energy of Microwave oven & they try to align themselves in same direction of EM Field of microwave oven.

Ans- Because in simple or blank kraft paper, voids are also present which are having air, and air is very bad conductor of heat.

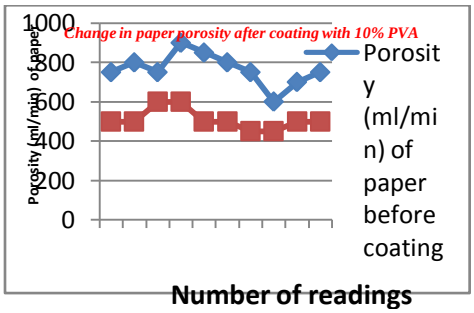
Value of heat conductivity for air is very less, so it will not allow the efficient propagation of heat, generated via dielectric heating caused by water molecules in simple blank paper to the maize kernels, which in turn will cause reduction in popping efficiency.

But when we coat paper with PVA solution, then that PVA solution fill those air voids of paper and now after coating in those air voids there would be PVA molecules in place of air voids. So heat transfer rate for that paper will increase automatically, which will increase popping efficiency for coated paper. Following data and graph will support this point.



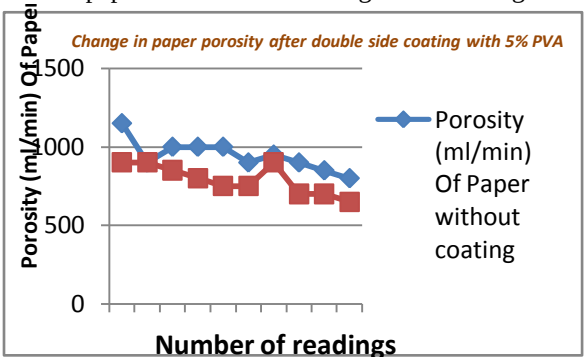


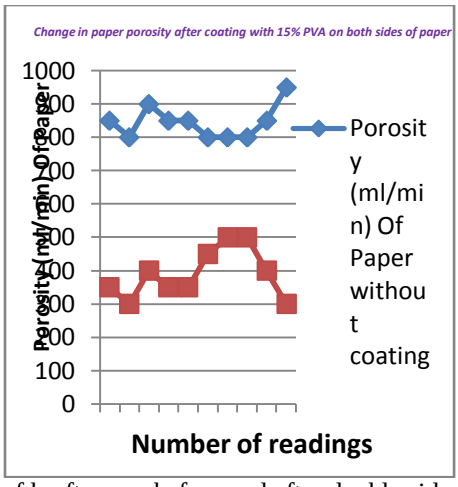
Graph 3:- Change in porosity of kraft paper before and after single side coating with 5% PVA Solution



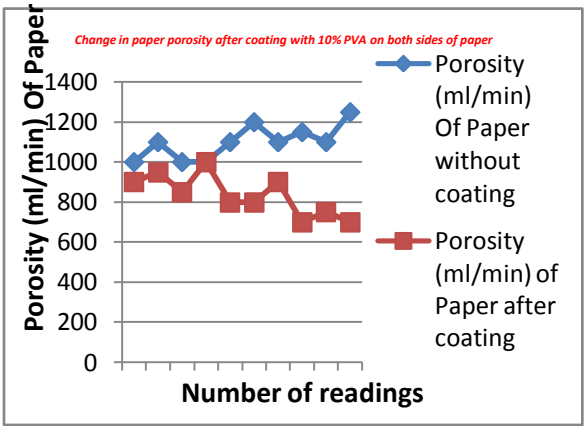
Graph 4:- Change in porosity of kraft paper before and after single side coating with 10% PVA Solution.

Graph 5:- Change in porosity of kraft paper before and after single side coating with 15% PVA Solution.





Graph 6:- Change in porosity of kraft paper before and after double side coating with 5% PVA Solution



Graph 7:- Change in porosity of kraft paper before and after double side coating with 10% PVA Solution

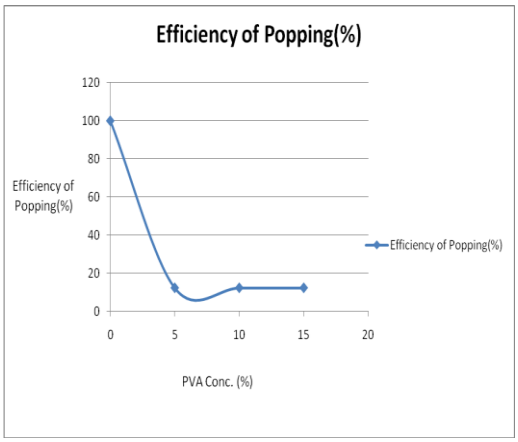
Graph 8: Change in porosity of Kraft paper before and after double side coating with 15% PVA Solution

All the above depicted graphs and table are suggesting that porosity of kraft paper is reduced significantly after coating with PVA solution. Reduction in porosity means reduction in air voids (**means bad conductor of heat is being replaced with a polar molecule i.e. PVA**). All these factors will increase propagation of heat through paper after coating.

Q. 4. Why do only outer side coating is producing better popping result but inner side and double side coatings are not producing such encouraging result?

Ans- Because **outer side coating** is producing heat due to dielectric heating of PVA & now that heat has to be transferred through a thin kraft paper to maize kernels. More amount of heat is being transferred to maize kernels which increases popping efficiency.

In **inner side coating** basically heat is being produced due to water molecules present in kraft paper and that heat produced will be in very low amount, as water is present in very low amount in paper i.e. 4%. That small amount of heat produced now will have to face resistive barrier of PVA coating on inner side. So very less amount of heat is being transferred to maize kernels in case of Inner coating. This is the reason for low popping efficiency in case of inner coating.



In **double side coating**, heat produced due to outer layer will have to face more resistance (first due to paper and second due to inner side coating of PVA). Means in double side coating, heat produced by outer layer of coating will lose its energy in passing through two resistive barrier. Now very less amount of heat will reach to maize kernels which will cause reduction in popping efficiency.

Q. 5 Why only 10% PVA coating is producing desirable results (high popping efficiency) among 5%, 10% & 15% PVA solutions?

Ans- Beacause 10% is the concentration at which PVA is neither too viscous nor very diluted. So, it fills the air voids in paper in a moderate way and increases the popping efficiency because heat transfer rate increases due to presence of polar PVA molecules in air voids of paper.

In case of 5 % PVA solution, (which is very diluted) isn't able to fill the air voids of paper in a proper way, which doesn't cause significant increase in heat transfer (because amount of polar molecules of PVA will be less due to low concentration of PVA) as well as popping efficiency.

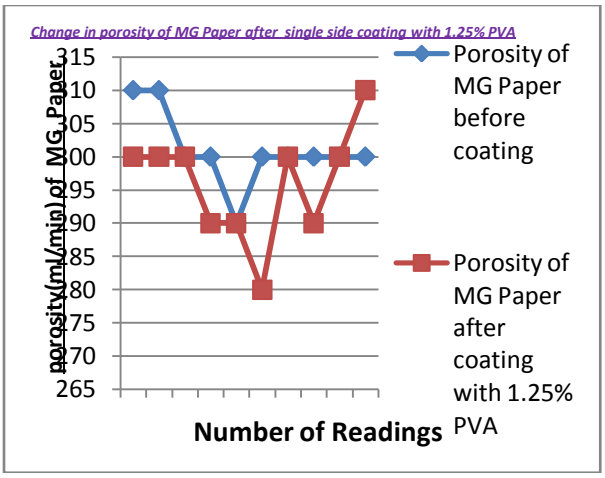
In case of 15% PVA solution which is very thick solution, again is not able to fill the paper voids during coating. Which means improper filling of air voids of paper and which in turn causes poor popping efficiency.

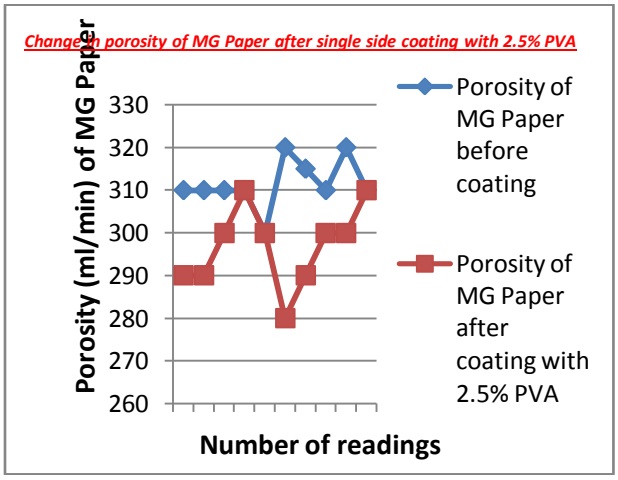
Q. 6 When Popping results with MG (Machine Glaze) paper were observed, then it was found that MG paper produces better popping results without PVA coating.

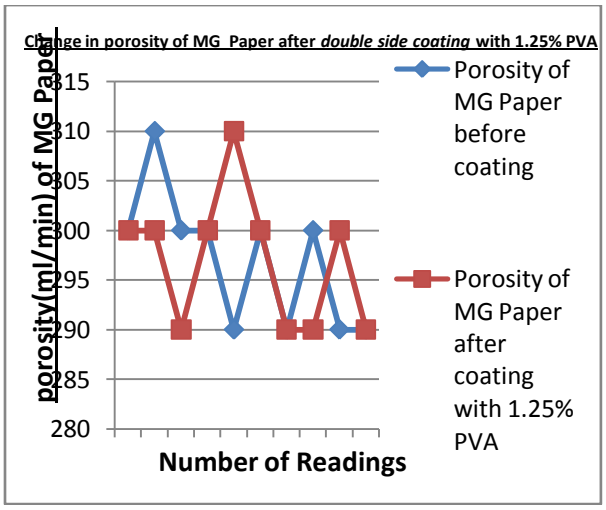
Graph 9: Popping efficiency of kraft paper envelope with 5%, 10% & 15% PVA outer side coating

This is opposite to popping results with kraft paper, explain why?

Ans- MG paper is less porous than kraft paper and its porosity doesn't change to greater extent even after c oating with PVA solution. It means amount of air present in MG paper before coating was equal to amount of air after coating with PVA solution. This can be proved by following graphs and tables:-



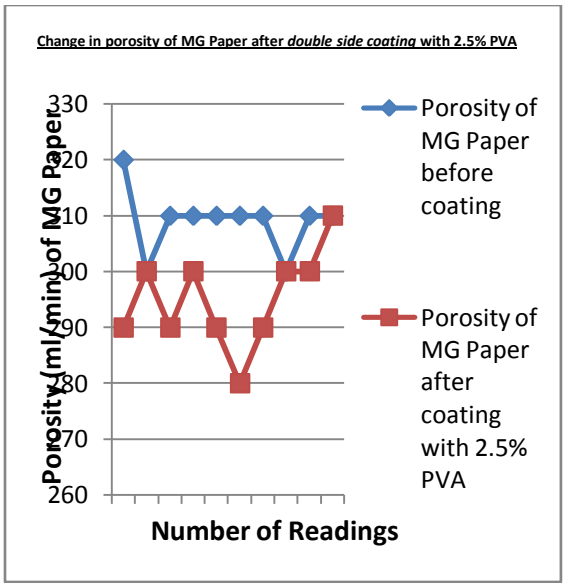




Graph 10:- Change in porosity of MG paper before and after single coating with 1.25% PVA Solution.

Graph 11:- Change in porosity of MG paper before and after double side coating with 1.25% PVA Solution.

Graph 12:- Change in porosity of kraft paper before and after single side coating with 2.5% PVA Solution.



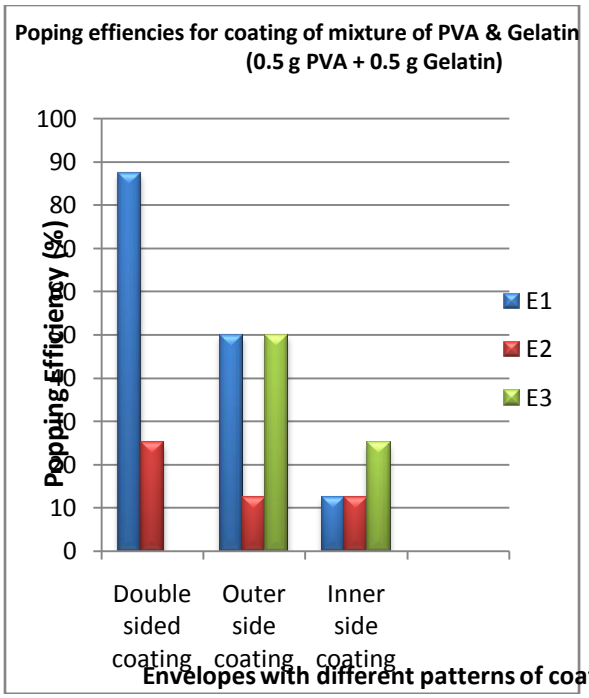
Graph 13:- Change in porosity of kraft paper before and after double side coating with 2.5% PVA Solution.

Air amount in MG Paper before coating was approximately equal to Air amount in MG Paper after coating. That means heat transfer will not be improved by a greater extent even after coating, because it will have to face same resistance of air as it was facing before coating. All the above mentioned empirical data support this.

Popping Efficiency didn't improved but decreased also, because film thickness reduced the penetration depth. The penetration depth (Dp) of the materials used to denote the depth at which the power density of microwave irradiation is reduced to 37% (i.e., l/e) of its initial value at the surface of the material.

Q.7 What would be the popping results when we do double side coating with lower concentration of PVA (such as 1.25 % PVA & 2.5 % PVA) on kraft paper?

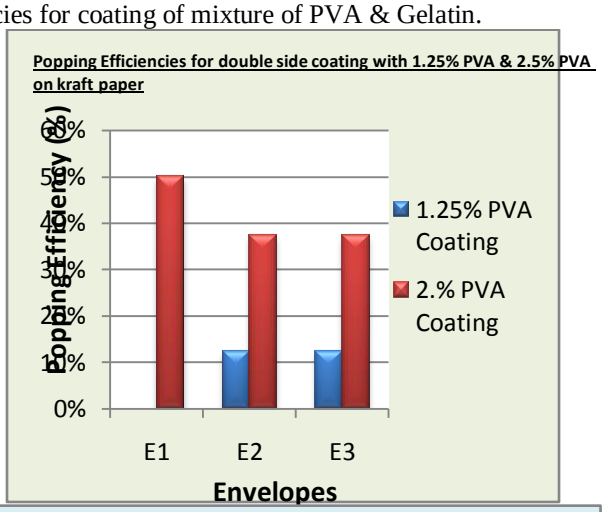
Ans- Above mentioned experimental results are clearly telling the same story that double side coating does not produce encouraging results in terms of popping efficiency because *"In **double side coating**, heat produced due to outer layer will have to face more resistance (first due to paper and second due to inner side coating of PVA). Means in double side coating, heat produced by outer layer of coating will lose its energy in passing through two resistive barrier. Now very less amount of heat will reach to maize kernels which will cause reduction in popping*

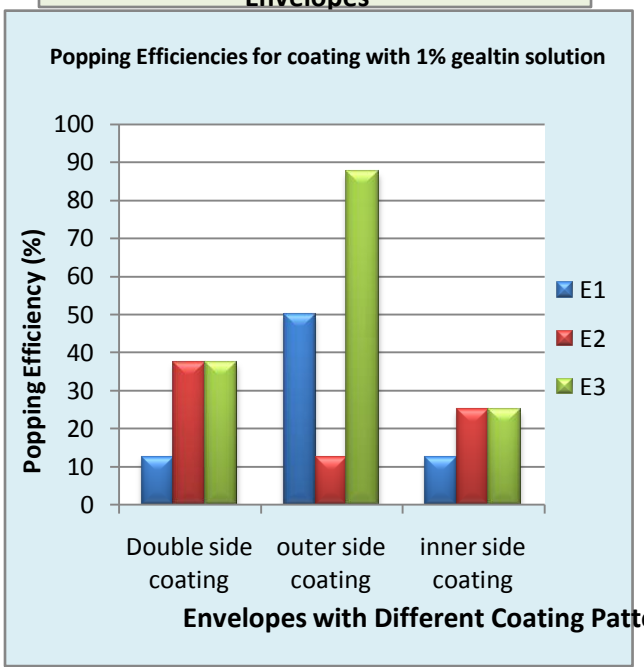


efficiency". Another reason for poor popping efficiencies in both the cases is that, here concentration of PVA is very less i.e. 1.25 % & 2.5 %, which means lesser amount of polar groups are present for dielectric heating. All these reason will ensure lower generation of heat, and lower generation of heat means lower popping efficiency.

What happens when we use PVA with other polymers?

Graph 14:- Popping efficiencies for coating of mixture of PVA & Gelatin.





Graph 15:- Popping efficiencies for coating of 1% Gelatin

It is clear that Gelatin alone and with PVA, isn't producing convincing results

because Here in gelatin polar group present is ketone, which is less polar than Hydroxyl group[9] of PVA , So less dielectric heating lead to less popping efficiency.

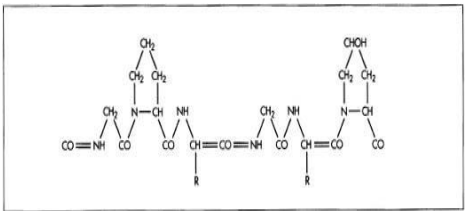
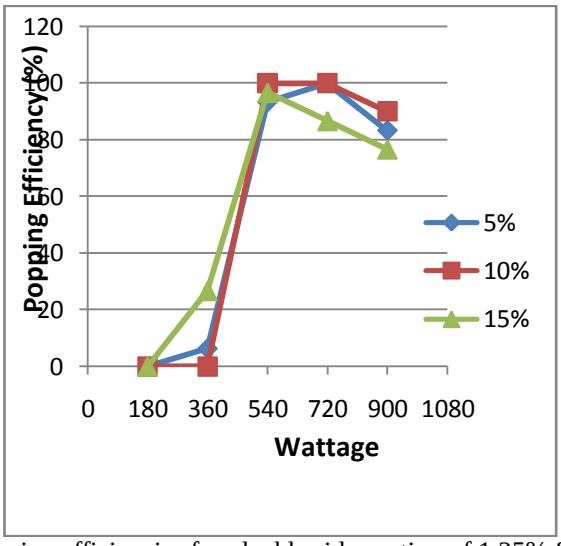


Fig 13: -Structure of Gelatin[8]

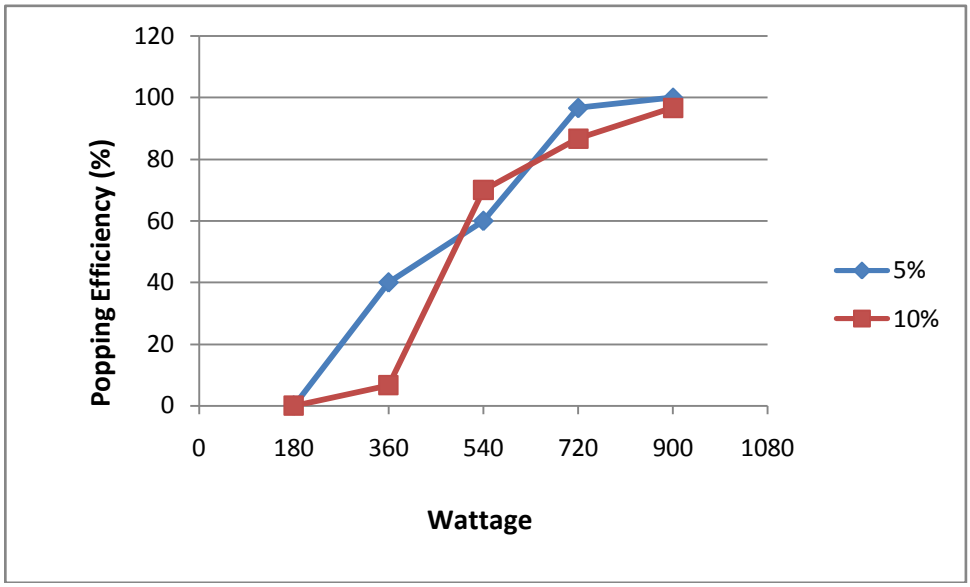
How popping efficiency will change if we use lower concentration of PVA i.e. 1.25% & 2.5%?



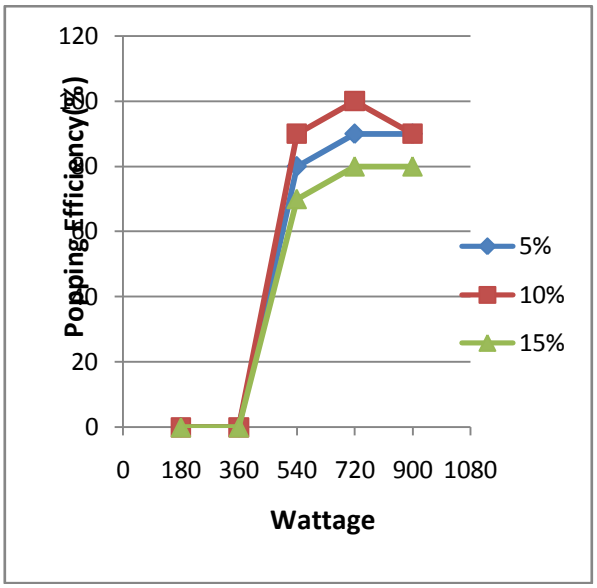
Graph 16:- Popping efficiencies for double side coating of 1.25% & 2.5% Gelatin.

Double side coating with 1.25 % & 2.5 % PVA solution is not producing encouraging popping efficiency. PVA concentration is very low, which means lesser amount of polar group and which lead to Low Popping Efficiency.

Graph 17:- Popping Efficiencies of envelope coated with 5%, 10% and 15% PVA of Mw 1,24,000 PVA, at different wattage of microwave oven.



Graph 18:- Popping Efficiencies of envelope coated with 5%, and 10% PVA of Mw 85,000 PVA, at different wattage of microwave oven.



Graph 19:- Popping Efficiencies of envelope coated with 5%, 10% and 15% PVA of Mw 1, 24,000 PVA, at different wattage of microwave oven.

Cost Analysis:-

It includes the raw material cost, operating cost and labour cost.

Calculations for raw material cost are as following:-

- Surface area i.e. {2(length*breadth + length*height + breadth*height)} of paper used in manufacturing of Microwave popcorn bag is about 0.155 m^2
- Outer side coating of 10 % PVA solution is giving best result in terms of popping efficiency of popcorns.
- Coat weight (*amount of PVA solution applied on unit area of paper*) for 10 % PVA solution is about 2.5 grams/$metre^2$

i.e.

For 1 $meter^2$ of paper, Amount of PVA required is = 2.5 grams
For 0.155 $meter^2$ of paper, Amount of PVA required will be = 2.5 * 0.155 grams
= 0.3875 grams

Now,
cost for 500 grams of PVA is = 480 rupees
Cost of 1 grams of PVA will be = 480/500 rupees
Cost of 0.3875 grams of PVA will be = (480/500)* 0.3875 Rs.
= 0.372 Rs.

Total cost of envelope = [(Cost of Kraft paper for 0.155 m^2 area) + (Cost of 0.3875 grams of PVA needed to coat on 0.155 m^2 area)]
= 0.5 rupees + 0.372 rupees
= 0.872 rupees
Now this is the raw material cost, for manufacturing of MPB (Microwave Popcorn Bag).

Calculations for operating cost are as following:-
Operating cost includes the electricity consumption of coater and magnetic stirrer.
Cost of 1 unit electricity in U.P. is = 3.78 rupees
Cost of 1 unit electricity in Delhi is = 4.44 rupees
We are taking cost of 1 unit of electricity as ~ **4 rupees**
Power of coater is 50 W[17], and 1 unit of electricity means 1 kWh of electricity.
Time taken in coating of 1 envelope is about 30 seconds. So, in 30 seconds coater will consume = (50/1000)* (30/3600) kWh electricity
= 0.00416 kWh

= 0.004 unit of electricity

Now cost of electricity consumption by coater for 1 envelope will be = 0.004*4 rupees
= **0.016 rupees**

In the same way we can calculate power consumption by magnetic stirrer for 1 envelope.

Power of magnetic stirrer is 250 W.[18, 19]

Time taken in preparation of solution for coating on envelope is about 2 hours. So, in 2 hours magnetic stirrer will consume = (250/1000)* (2) kWh
= 0.5 kWh
= 0.5 unit of electricity

Now cost of electricity consumption by magnetic stirrer will be = 0.5*4 rupees
= **2 rupees**

Calculation of labour cost:-

For 8 hours, labour cost is = 300 rupees
For 1 hours, labour cost is = 300/8 rupees
(time required for preparation one envelope from coating to packaging requires around 5 mins)
So, for 5 mins, labour cost will be = (300/(8*60))*5 rupees
= **3.125 rupees**

Total cost of 1 envelope will be = raw material coast + electricity cost + labour cost
= 0.8 + {0.016+ 2} + 3.125 rupees
= 5.94 rupees ~ **6 rupees**

Pay Back Period:-

It is the time period in which we will get the total amount of investment back, which we have done in any project.

Let initially we will require following items (given with their price value) to start this packaging business:-

1. Coater = 2699 pounds
   = 2699 * 88 =2,37,512 Rs.
2. 200 m^2 paper = **645.16** rupees
3. 500 gm PVA = **480** rupees
4. Magnetic stirrer (e,g. C-MAG MS4 IKAM AG type)[20] = **20,400** rupees
5. Labour = **300** rupees/ day
6. Glass wares (e.g. 300 ml) = **300** rupees[21]

Now electricity consumption by Coater for coating of 1 envelope is = 0.004 unit
For coating of (200 m^2/0.155 m^2)= 1290 envelopes it will require = 5.16 units
Cost of electricity, caused by coater, in coating of 1290 envelopes will be = 5.16 * 4 rupees
= **20.64 rupees**

Now,
If magnetic stirrer work for 2 hours then power consumption by it is = 0.5 units of electricity
" " " " " 1 " " " " " " = (0.5/2) " "
" " " " " 240 " " " " " " = (0.5/2)* 240 " "
= 60 units of electricity

Cost of 60 units of electricity caused by magnetic stirrer, i.e. for 1 month will be around = 60*4 rupees
= **240 rupees**

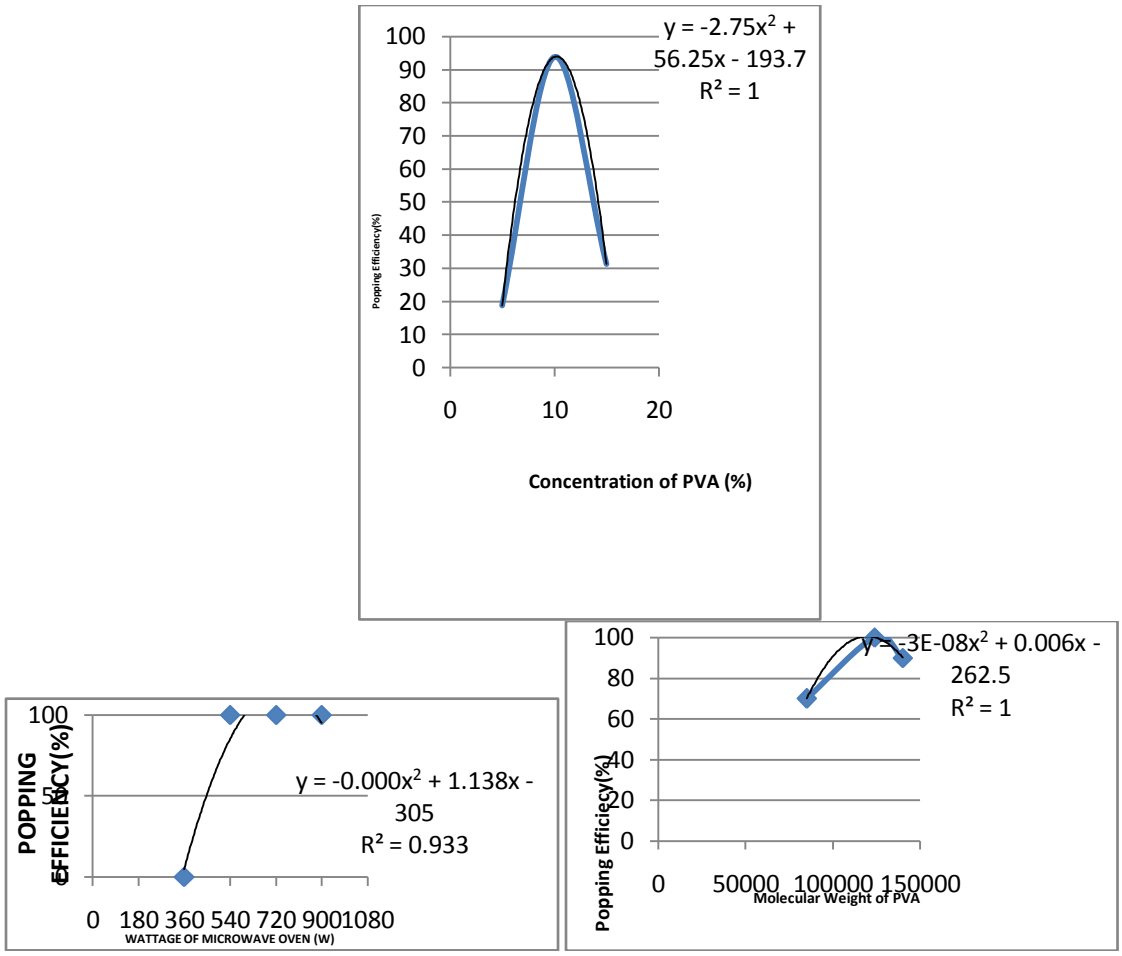
Suppose we are preparing 1290 envelopes in a month from 200 m^2 paper.

So, initial investment for 1 month will be of = (2699 pounds) + 645.16 +480+ 20,400 + 9000 +300+ 20.64+ 240 rupees
= 2, 68,381.8 rupees

From this coater, magnetic stirrer will require only one time investment (i.e. **2,57,912 rupees**) and monthly expenses will be of paper, electricity consumption by coater, electricity consumption of magnetic stirrer, PVA etc. (i.e. **1385.96 rupees**)

We are preparing 1290 envelopes, and we are planning to sell our envelope at 20 rupees. So profit from 1 envelope will be about 14 rupees.

Total profit from 1290 envelopes would be **= 1290* 14**



=18,060 rupees

After 16 months, total profit will be = 18,060 * 16 rupees
= 2,88,960 rupees

For 16 months we will have to bear 1385 * 16= 22,160 rupees expenses
Initial investment was = 2,57,912 rupees

Total expenses = 22,160 + 2,57,912 = 2,80,072 rupees

So, after 16 months we are observing that total expenses ~ total profit

Now cost of one envelope is around 6 rupees. If we sell it at the price of 20 rupees then we will get back our investment within 16 months.

Development of Numerical Model for Popping Efficiency

Graph 1: Relation between Popping Efficiency and concentration of PVA, keeping wattage and molecular weight of PVA constant

Graph 2: Relation between Popping Efficiency and molecular weight of PVA, keeping wattage and concentration of PVA constant

Graph 3: Relation between Popping Efficiency and wattage of microwave, keeping molecular weight and concentration of PVA constant

Now, we are getting three equations in which we are keeping 2 parameters constant. Our aim is to develop a single equation, showing variation of popping efficiency with wattage of microwave oven, molecular weight of PVA and concentration of PVA coating on envelope.

For this we have to combine each equation, to show the following relation in a mathematical model:-

Popping Efficiency = f (Concentration of PVA, Molecular weight of PVA, Wattage of microwave oven)

Approach for doing this,
We can differentiate each equation (considering one factor and keeping other 2 factors constant) and will combine them via triple integration.

Let

y in all three equations is now A, which is representing popping efficiency;
x and x^2 of first equation is representing concentration of PVA;
x and x^2 of second equation is now y, which will represent molecular weight of PVA;
x and x^2 of third equation is now z, which will represent wattage of microwave oven.
Now differentiating these 3 equations according to the new nomenclature:-

Let A is the popping efficiency and we are differentiating first equation with respect to x , keeping y and z constant which are representing that we are keeping 2 parameters constant e.g. wattage and molecular weight of PVA. Like this we will develop differentiation equation for graph 2 and 3 also.
Differentiation of equation of first graph will give:-

$\frac{dA}{dx} = -4.5x + 56.25$……..equation 1

Differentiating equation of second graph:-

$\frac{dA}{dy} = -(6 * 10\text{^}0.8)x + 0.006$……..equation 2

Differentiating equation of third equation:-

$\frac{dA}{dz} = 1.138$……..equation 3

Now integrating equation 1, 2 and 3:-

$$\iiint \frac{dA}{dx} * \frac{dA}{dy} * \frac{dA}{dz} = \iiint (-4.5x + 56.25)\left((-6 * 10^{0.8})x + 0.006\right)(1.138)$$

After solving this we will get an equation like:-

$$\mathbf{A^3} = \iiint (193.86x - 0.030y - 2422.93)dx.dy.dz$$

We can vary value of x, y and z to get different values of popping efficiencies at different-2 parameters.
Where, A is popping efficiency of envelope;
X is concentration of PVA solution for coating on envelope;
Y is molecular weight of PVA;
Z is wattage of microwave oven.

Summary:-

Microwave popcorn bags are industrial oriented products and these are used in our day today life. Available microwave popcorn bag are performing good in terms of storage and they maintain flavour of food material kept inside them. But these have some serious severe health related concerns also and beside these concerns, their existing manufacturing technology is very costly. So there is great need to find out novel ways to manufacture these bags so that they can be prepared at lower cost with no health harms.

We have tried an attempt to do so, by replacing aluminium foil used in modern microwave popcorn bags with 10% PVA solution's coating. We have found that when this coating is done on outer side of envelope then it gives best results in terms of cooking efficiency. We have also find out that optimized cooking time for food material inside such bags is, 3 minutes. Use of PVA solution will definitely reduced cost of manufacturing of these microwave popcorn bags. PVA is not health hazardous and it is currently being used in various food items such as in manufacturing of chewing gum. Use of PVA also eliminates the risk of cancer which was major problem in long term use..
If we plan to start a set up for manufacturing of popcorn bag according to our formulation then payback period according to n estimate will be of **16 months**.

References:-

1. "(wo/2001/053167) microwave food package". *IP Services > PATENTSCOPE > Patent Search*. Wipo.
2. Jacky a. Rosati and kenneth a. Krebs U.S. Environmental Protection Agency, National Risk Management Research Laboratory, RTP, NC 27711 and XIAOYU LIU U.S. Environmental Protection Agency, National Risk Management Research Laboratory, RTP, NC 27711; Arcadis G & M, RTP, NC 27711, Emissions from Cooking Microwave Popcorn, 47:701–709 (2007)
3. N. V. Petrova, A. M. Evtushenko, I. P. Chikhacheva, V. P. Zubov, and I. V. Kubrakova, Effect of Microwave Irradiation on the Cross-Linking of Polyvinyl Alcohol, June 2005.
4. Kubrakova, I.V., *Usp. Khim.*, 2002, vol. 71, no. 4, pp. 327_340.
5. Dikusar, M.A., Kubrakova, I.V., Chinarev, A.A., and Bovin, N.V., *Bioorg. Khim.*, 2001, vol. 27, no. 6, pp. 457_ 461.
6. Perreux, L. and Loupy, A., *Tetrahedron*, 2001, vol. 57, pp. 9199_9223.
7. Lidstrom, P., Tierney, J., Wathey, B., and Westan, J., *Tetrahedron*, 2001, vol. 57, pp. 9225_9283.
8. Wittaker, A.G. and Mingos, D.M.P., *J. Microwave Power Electromagn. Energy*, 1994, vol. 29, no. 4, pp. 195_219.
9. S.K.Saxena, POLYVINYL ALCOHOL (PVA), Chemical and Technical Assessment (CTA), © FAO 2004.
10. Vinyl acetate, polyvinyl acetate and Polyvinyl alcohol. In: Some Monomers, Plastics, and Synthetic Elastomers, and Acrolein. IARC Working group, feb. 7-13,1978,Lyon, France. World Health Organization (WHO). International Agerny for Research on Cancer (IARC); Lyon, France. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man, Vol. 19, pp. 341-366.
11. Paul Whittaker, Jane J. Clarke, Richard H.C. San c, Timothy H. Begley, Virginia C. Dunkel, Evaluation of the butter flavoring chemical diacetyl and a fluorochemical paper additive for mutagenicity and toxicity using the mammalian cell gene mutation assay in L5178Y mouse lymphoma cells, 3 June 2008.
12. Kreiss, K., Gomaa, A., Kullman, G., Fedan, K., Simoes, E.J., Enright, P.L., 2002. Clinical bronchiolitis obliterans in workers at a microwave-popcorn plant. N. Engl. J. Med. 347, 330–338.
13. Kreiss, K., 2007. Flavoring-related bronchiolitis obliterans. Curr. Opin. Allergy Clin. Immunol. 7, 162–167.
14. Bjeldanes, L.F., Chew, H., 1979. Mutagenicity of 1,2-dicarbonyl compounds: maltol, kojic acid, diacetyl and related substances. Mutat. Res. 67, 367–371.
15. Marnett, L.J., Hurd, H.K., Hollstein, M.C., Levin, D.E., Esterbauer, H., Ames, B.N., 1985. Naturally occurring carbonyl compounds are mutagens in Salmonella tester strain TA104. Mutat. Res. 148, 25–34.
16. T. H. Begley, k. White, p. Honigfort, m. L. Twaroski, r. Neches, & r. A. Walker, Perfluorochemicals: Potential sources of and migration from food packaging, Food Additives and Contaminants, October 2005; 22(10): 1023–1031.
17. http://www.zehntner.com/products/categories/application/zaa-2300#technical-specification
18. http://www.sigmaaldrich.com/catalog/product/aldrich/z671770?lang=en&region=IN
19. http://www.snp-scientific.com/images/bank/IKA%20C-Mag%20pdf001.pdf
20. http://www.ika.in/owa/ika/catalog.product_detail?iProduct=3582200&iCS=1&iProductgrou p=188&iSubgroup=1
21. http://www.ebay.com/sch/Lab-Glassware-/11812/i.html (Placeholder1)