DEVELOPMENT OF USER INTERACTIVE SOFTWARE ‘INTER-PACK’ FOR FOOD PACKAGING SYSTEM DESIGN

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End Autumn Semester Report submitted to
Indian Institute of Technology Kharagpur
for the partial fulfillment of the requirements
for the award of the degree of

Bachelor of Technology
in
Agricultural and Food Engineering

by

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Under the guidance of

Prof. S.K. Das

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ACKNOWLEDGEMENT

I would like to take this opportunity to express my gratitude to Prof. S.K. Das for his guidance, monitoring and encouragement throughout this project. This instilled in me the confidence to work on this project.

I would like to extend my gratitude to Mr. Mukesh Prajapati, my senior, department of Agricultural and Food Engineering for helping me out with the doubts regarding project. I would also like to thank the faculty of Agricultural and Food Engineering department for their valuable suggestions and suggestions for improvement.

Date: Abhijeet Singh

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LIST OF ABBREVIATIONS

Abbreviation	Usage
d.b	Dry Basis
GUI	Graphical User Interface
IDE	Integrated Development Environment
GAB	Guggenheim-Anderson-DeBoe
MSI	Moisture Sorption Isotherm
BET	Brunauer, Emmett and Teller
PVDC	Polyvinylidene Chloride
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene

ABSTRACT

Food stability and safety are the main aims of packaging. For efficient packaging system design one should know the shelf life and cost of packaging. This shelf life can be determined with the help of Moisture Sorption Isotherm (MSI), the permeability values of the packaging material. To model the MSI we use the GAB model.

This project aims to develop software to help in the designing process. To enable ‘Inter-pak’ in calculating the shelf life, we develop the required databases. The databases required were packaging material permeability database, GAB model constants database, price of packaging material database, bulk density of food material database. Using these databases ‘Inter-pak’ calculates the shelf life of food material in days and the cost of packaging in Rs. ‘Inter-pak’ also provides the user the option of updating all the databases, changing the thickness of packaging material, adding one or more layers. The user has the option of keeping the temperature constant or variable. To better model the variation of temperature during the day, ‘Inter-pak’ pulse variation of temperature during the day.

Keywords: Gab model, Moisture Sorption Isotherm, food material database, packaging database, temperature variation, packaging design

CHAPTER 1: INTRODUCTION

1.1 Introduction

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Packaging assists the preservation of the world's resources through the prevention of product spoilage and wastage, and by protecting products until they have performed their function. The principal roles of packaging are to contain, protect/preserve food and inform the user.

A barrier from oxygen, water vapour, dust, etc., is often required. Permeation is a critical factor in design. Some packages contain desiccants or Oxygen absorbers to help extend shelf life. Modified atmospheres or controlled atmospheres are also maintained in some food packages. Keeping the contents clean, fresh, sterile and safe for the intended shelf life is a primary function.

Packages and labels communicate how to use, transport, recycle, or dispose of the package or product. With pharmaceuticals, food, medical, and chemical products, some types of information are required by governments. Some packages and labels also are use, or consumption. Shelf life is the recommendation of time that products can be stored, during which the defined quality of a specified proportion of the goods remains acceptable under expected (or specified) conditions of distribution, storage and display.

Shelf life is most influenced by several factors: exposure to light and heat, transmission of gases(including humidity), mechanical stresses, and contamination by things such as micro-organisms. Using Moisture Sorption Isotherm, we can calculate the water activity of the food material and whether it is safe for consumption. There is a variety of packaging material which can be used for packaging.

For designing the packaging system, a software is need to interact with the user calculate the shelf life and cost of packaging, and allow the user to make changes as desired to the packaging.

1.2 Need For Such Software For Food Packaging Design

'Inter-pak' is user friendly and interactive. The user interface allows for easy entering of data and viewing of the output. Also, helps in the decision making process

As the values of time and cost are available the user can better make the decision whether to choose that material or he/she wants to change. It gives a n estimate of the shelf life and cost quickly which would otherwise be tedious to calculate

We can easily vary the input parameters and see how they affect the shelf life and cost i.e. simulation can be done. It is portable means it can be carried and used in most systems and does not need to be installed.

1.3 Objectives:

- To pool the database of packaging material, GAB constants for food material, bulk density of food material, price of packaging material
- To use this database to design food packaging system using a user-interactive program

CHAPTER 2: LITERATURE REVIEW

2.1 Food Stability

Food stability is one of the main concerns of the packaging industry. The aim is to increase the shelf life keeping the cost of packaging in mind. Safety of food is mainly determined by the presence of microorganisms. Growth of microorganisms is influenced by the moisture content of the food material.

The free energy of water is related to its water activity. Water activity is an important consideration for food product design and food safety. Below a certain water activity microorganisms cease to grow. The value is usually taken as 0.6. Food is considered safe as long as its water activity is less than 0.6. The variation of water activity with moisture content of the food samples is thus important from a food safety perspective. This is modelled with the help of moisture adsorption isotherms. Each isotherm is for a constant temperature.

There are certain models equations to mathematically relate the water activity and relative humidity. These equations are known as equations of MSI. BET equation, Langmuir equation, GAB equation are a few among them. Using these we can calculate the water activity and hence the shelf life of food materials.

2.2 Water Activity

It is defined as the vapour pressure of a liquid divided by that of pure water at the same temperature. As the temperature increases, a_w typically increases, except in some products with crystalline salt or sugar. Water migrates from areas of high a_w to areas of low a_w.

Definition of a_w:

$$a_w \equiv p/p_0 \tag{2.1}$$

where p is the vapour pressure of water in the substance, and p_0 is the vapour pressure of pure water at the same temperature.

When an equilibrium condition is reached the partial pressure of vapour in the atmosphere is equal to the vapour pressure of vapour in the food material.

2.3 Moisture Sorption Isotherm

At equilibrium, the relationship between water content and equilibrium humidity of a material can be displayed graphically by a curve, the so called moisture sorption isotherm. For each humidity value, a sorption isotherm indicates the corresponding water content value at a given, constant temperature. If the composition or quality of the material changes, then its sorption behaviour also changes. Because of the complexity of sorption processes, the isotherms cannot be determined by calculation, but must be recorded experimentally for each product.

The relationship between water content and water activity is complex. An increase in aw is usually accompanied by an increase in water content, but in a non-linear fashion. This relationship between water activity and moisture content at a given temperature is called the moisture sorption isotherm. These curves are determined experimentally and constitute the fingerprint of a food system.

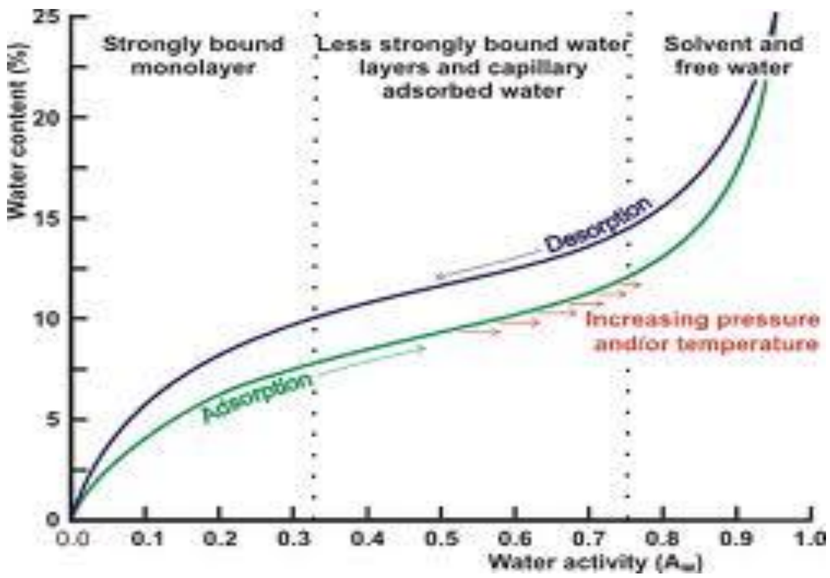


Figure 2.1. Moisture sorption isotherm

2.4 Mathematical Equations of Sorption Isotherm

Langmuir Equation

Langmuir proposed the following physical adsorption model on the basis of unimolecular layers with identical and independent sorption sites, and which is expressed as it is shown :

$$a_w\left(\frac{1}{M_w} - \frac{1}{M_0}\right) = \frac{1}{M_0} \tag{2.2}$$

where M_w is the equilibrium moisture content (kg water/kg dry matter), M_0 is the monolayer sorbate content (kg water/kg dry matter) and C is a constant.

The extensions of the Langmuir's underpinning idea on multi-molecular layers result in the BET and GAB isotherms, which are able to describe sigmoidal shaped isotherms commonly observed in the case of food.

Bet Equation

The BET was first proposed by Brunauer, Emmett and Teller.

$$m = \frac{m_0 c a_w}{(1-a_w)(1-a_w+ca_w)} \tag{2.3}$$

where m_0 is the monolayer moisture content, which represents the moisture content at which the water attached to each polar and ionic groups starts to behave as a liquid-like phase. And, C is the energy constant related to the net heat of sorption; it is related to the difference between the molecules that sorb energy of the first layer and the other remaining layers. These constants are also the constant characteristic of the isotherm of sorption of monolayer of Langmuir. Almost in all cases, the deviation of the linearity of these graphs indicates that, at high vapour pressures, the amount adsorbed by the sorbent is lower than the one predicted by the isotherm

Gab Model

The sorption isotherms of biological and food materials are mostly of sigmoid shape. The GAB model is considered one of the most useful ones which in many simple sorption cases can be used for the approximation of the experimental data at water activity of up to 0.9. ‘GAB’ equations is presented as (Prothon,Ahrne et. al.(2003)) :

$$m = \frac{m_0 cKa_w}{(1-Ka_w)(1-Ka_w+cKa_w)} \tag{2.4}$$

m = moisture content (d.b)

a_w = water activity

m_0, c, K = three sorption parameters characterising the sorption properties of

the materials .

2.5 Permeation

Permeation is the penetration of a permeate (such as a liquid, gas, or vapour) through a solid, and is related to a material's intrinsic permeability.

The permeate always migrates to the lower concentration in three steps:

1. Sorption (at the interface): Gases, vapour or dissolved chemicals or suspended substances are adsorbed at the surface of the solid.
2. Diffusion (through the solid): The permeate penetrates the solid material through pores or molecular gaps.
3. Desorption: The adsorbate leaves the solid as a gas.

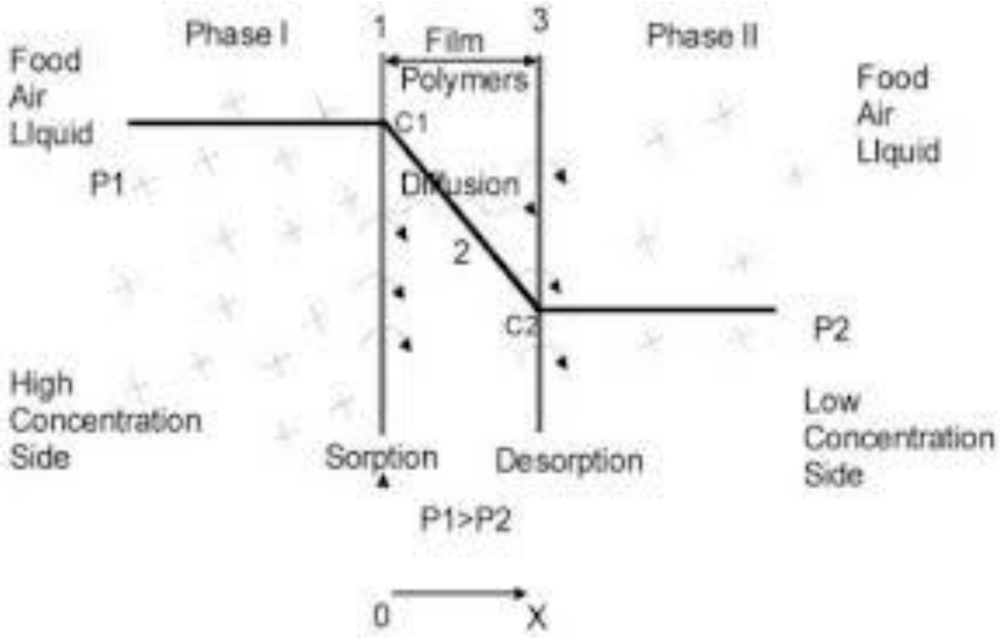


Figure 2.2. Permeation process

2.6 Diffusion of gases in solids

Fick's law is given as(geankoplis(1993)) :

$$N_A = \frac{D_{AB}(c_{A1}-c_{A2})}{z_2-z_1}$$
(2.5)

N_A = Flux of A, $kmol/\,m^2 s$

D_{AB} = Diffusivity of A in B, m^2/s

c_{A1}= Concentration of A at point 1, $kmol/\,m^3$

c_{A2} = Concentration of A at point 2, $kmol/\,m^3$

z_2-z_1 = thickness through which the gas diffuses, mm

The diffusion coefficient D_{AB} in the solid is not dependent upon the pressure of the gas or liquid on the outside of the solid.

$$c_{A1} = \frac{Sp_{A1}}{22.414}$$

$$c_{A2} = \frac{Sp_{A2}}{22.414}$$

S = Solubility m^3(STP)/m^3 solid Pa

So,

$$N_A(kmol/\, m^2 s) \;=\; \frac{P_{AB}(p_{A1}-p_{A2})}{22.414\times(z_2-z_1)} \tag{2.6}$$

When there are several solids 1,2,3….n, in series and L_1, L_2 ....….L_n. represent thickness of each,

$$N_A \;=\; \frac{(p_{A1}-p_{A2})}{22.414\times\sum_{i=1}^{n}\frac{L_i}{P_i}} \tag{2 .7}$$

where:

$(p_{A1} - p_{A2})$ = Pressure gradient, kPa

P_i = Water vapour permeability of i^{th} layer, m^3(STP) mm/ Pa m^2s

L_i = thickness of i^{th} layer, mm

CHAPTER 3: MATERIALS AND METHODS

3.1 Packaging Material Database Pool

Different packaging materials have different values of water vapour permeability. The choice of packaging material can significantly increase the shelf life. Another factor which plays a role is the cost of packaging.

For different packaging material a database of permeability values and the price is maintained in a text fie as 'watervapourpermeability.txt'. The user also has the option of updating this database.

3.2 Food Material Database Pool

The food material database consists of m_0, c, k values of the food material to be used in GAB equation. Different food materials have different values of the GAB parameters. The database is maintained in a text file: 'gab_parameters.txt'. It can be updated as and when required by the user.

'Inter-pak' also uses bulk density of the food material during calculations. The values of bulk density of food materials are maintained in a separate text file: 'bulk_density.txt'.

3.3 Values Entered By the User

1. Relative Humidity

   The relative humidity of the storage has an effect on the shelf life of the food product. Higher the relative humidity, higher the pressure difference across the packaging material and higher will be the moisture diffused.

2. Temperature
   Temperature also has an effect on the pressure difference created across the packaging material. Higher the temperature lower is the pressure difference and higher is the shelf life.

3. Material for Packaging

   The packaging material chosen has a major effect on the shelf life of a food product. Some materials are more pervious to water vapour than others. A material with low permeability value should be chosen to extend shelf life.

4. Mass of the food sample

   The mass of the sample is used for calculating the dimensions and for calculating the moisture content on dry basis. It has no direct effect on the shelf life.

5. Moisture content of the food sample

   Moisture content has a direct effect on the shelf life of a food product. Higher the initial moisture content the less is the expected shelf life of the product. This is because soon the critical point of water activity is reached and microbes start growing.

6. Dimensions of the sample

   They are used for calculating the cost of packaging. They have no effect on the shelf life of the product.

3.4 Programming Language Used

Programming language used is Java. This language is used because of its wide support for building Graphical User Interface (GUI).The Swing toolkit is used for building GUI. For writing code, compiling, debugging NetBeans IDE (Integrated Development Environment) is used.

Another reason for used of Java is that it is supported on wide number of platforms. Hence ‘Inter-pak’ can be run on any machine without installing.

3.5 Process Flow

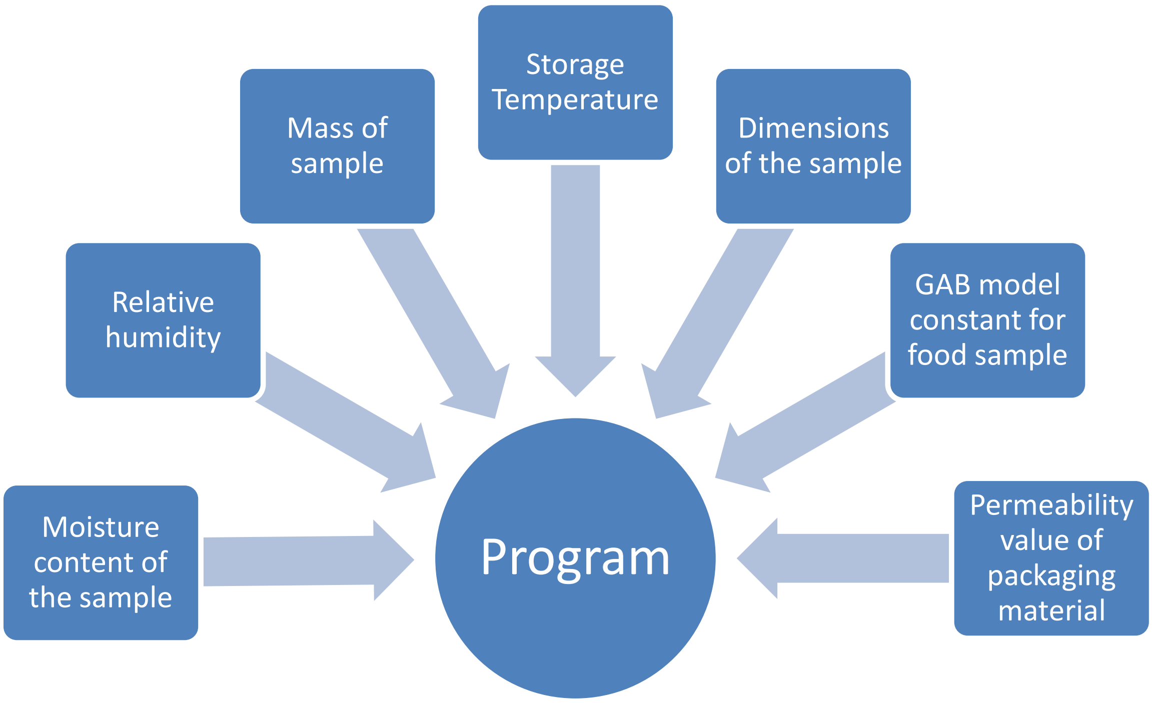


Figure 3.1. Inputs to ‘Inter-pak’

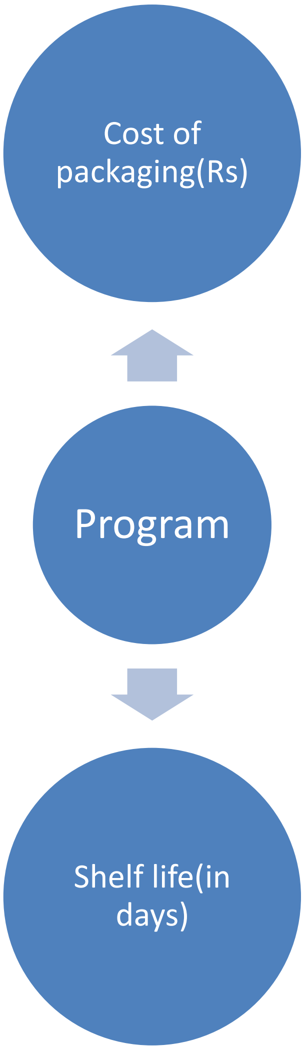


Figure 3.2. Outputs of ‘Inter-pak’

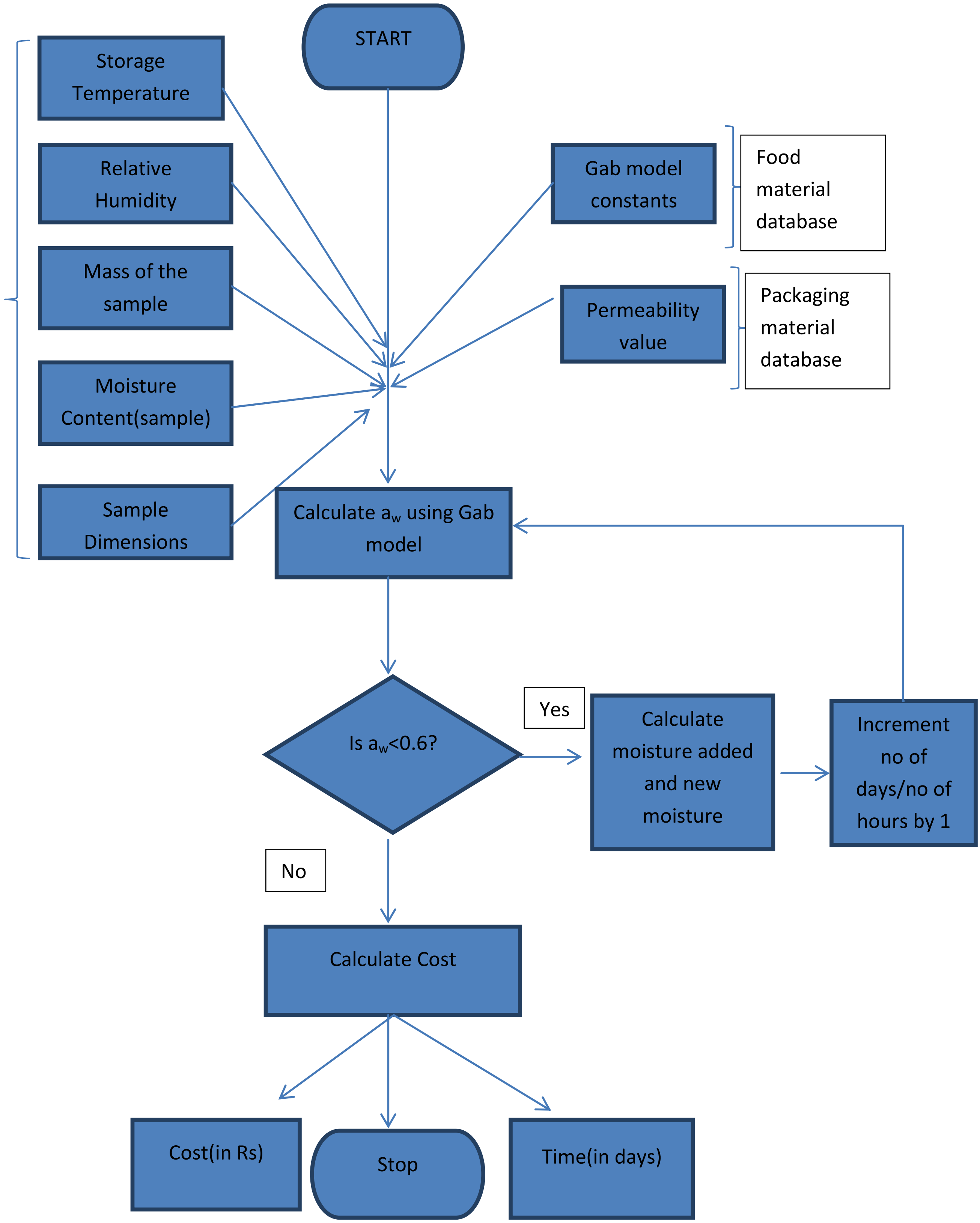


Figure 3.3. Program Flowchart

3.5 Calculations

Step 1 Calculation of water activity

We have the GAB model equation

$$m = \frac{m_0 c K a_w}{(1-Ka_w)(1-Ka_w+cKa_w)} \tag{3.1}$$

Multiplying and rearranging we get:

$$mK^2(1-c){a_w}^2 + \big((c-2)mK\big) - (m_0 cK)a_w + m = 0$$

$$B_2{a_w}^2 + B_1 a_w + B_0 = 0 \tag{3.2}$$

$$a_w = \frac{(B_1 \pm \sqrt{{B_1}^2 - 4B_0B_2})}{2B_2} \tag{3.3}$$

where

a_w = water activity, dimensionless

m_0, c, K = GAB equation constants

m = moisture content (d.b), dimensionless

$B_0 = m$

$B_1 = \big((c-2) \times m \times K\big) - (m_0 cK)$

$B_2 = m \times K^2 \times (1-c)$

Step 2 Calculating the inside and outside pressures

The equation for calculating saturation vapour pressure is given as:

$$ln(p_0) = 18.6556 - \frac{5217.635}{T} \tag{3.4}$$

$$P_{inside} = a_w \times p_0 \times 1000$$

$$P_{outside} = r.h \times p_0 \times \frac{1000}{100}$$

where:

p_0 = Saturated vapour pressure at temperature T, kPa

T = Storage Temperature, °C or K

Step 3 Calculation of the amount of moisture diffused

If $P_{outside} > P_{inside}$

$$N_{AB} = \frac{(P_{AB}) \times ((P_{outside} - P_{inside})}{22.414 \times t} \quad (3.5)$$

If $P_{outside} < P_{inside}$

$$N_{AB} = \frac{(P_{AB}) \times ((P_{inside} - P_{outside})}{22.414 \times t} \quad (3.6)$$

where:

P_{AB} = Water vapour permeability of packaging material, m^3(STP) mm/ Pa m^2s

$P_{outside}$ = Vapour pressure of water outside the packaging layer, kPa

P_{inside} = Vapour pressure of water inside the packaging layer (inside the food material), kPa

t = Thickness of the packaging layer, mm

Step 4 Calculation of the new moisture content

$$M = N_{AB} \times A \times 24 \times 3600 \quad (3.7)$$

Total mass = Wet mass + Dry mass

So, Dry mass = Total mass – Wet mass

$$m_{add} = \frac{M \times 18}{Dry\ mass} \tag{3.8}$$

$m = m + m_{add}$

where:

M = kmol of water diffused in that time

m_{add} = moisture added, % db

Step 5 Repeat steps 1, 2, 3 and 4 till a_w is less than 0.6

4.2 Test Cases

4.2.1 Updating the Food Material Database

Frame 1 Choosing the packaging material

This frame shows the packaging material chosen by the user from the drop down menu

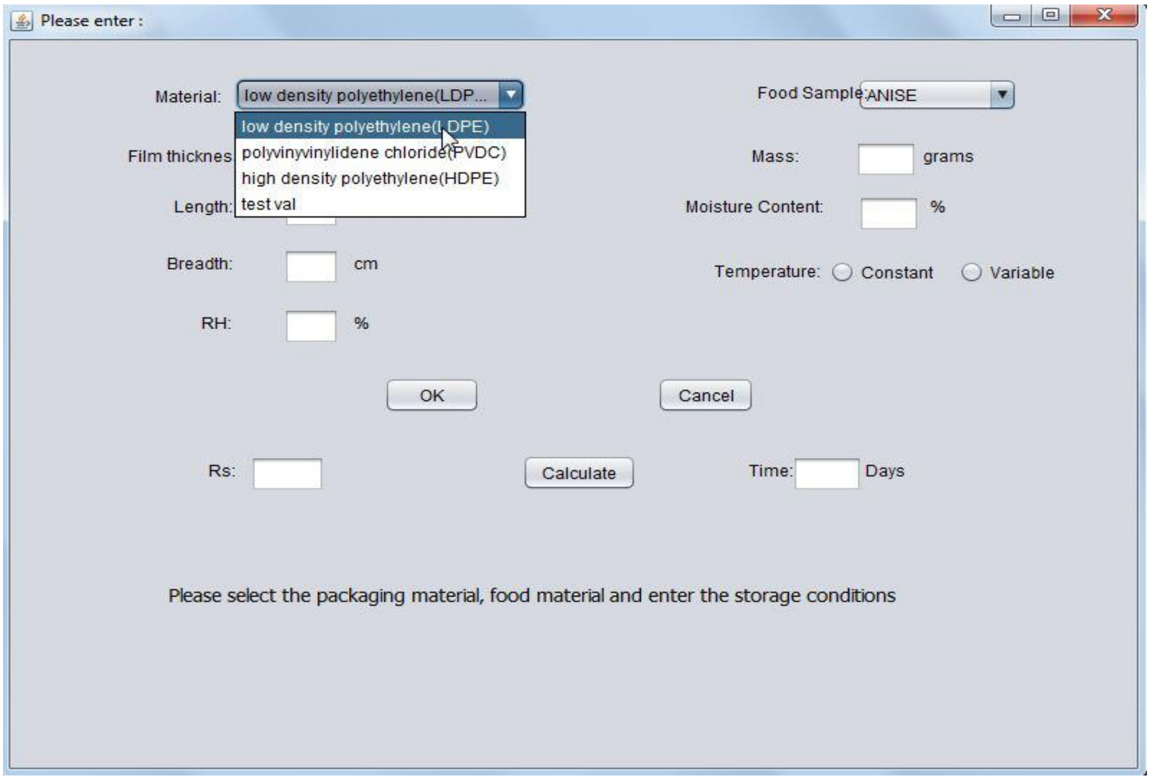


Figure 4.1. Choosing the packaging material

Frame 2 Choosing the food material (whose data is not in the database)

The user chooses a food material 'test val' whose data is not in the database

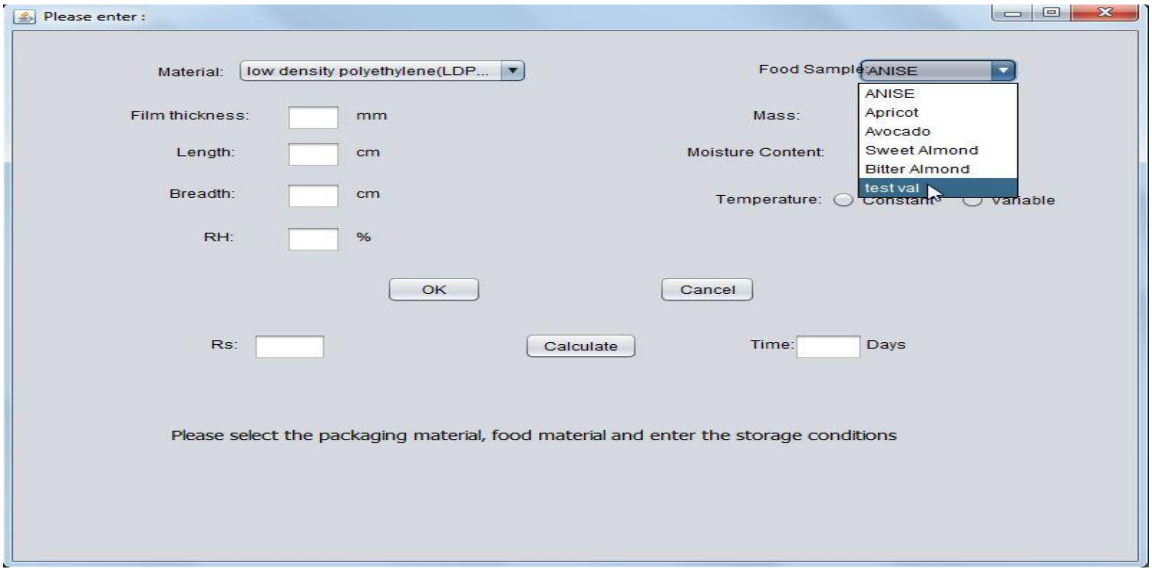


Figure 4.2. Choosing the food material (whose data is not in the database)

Frame3 Pop up box for user to enter the required values

This frame shows the rest of the values entered by the user

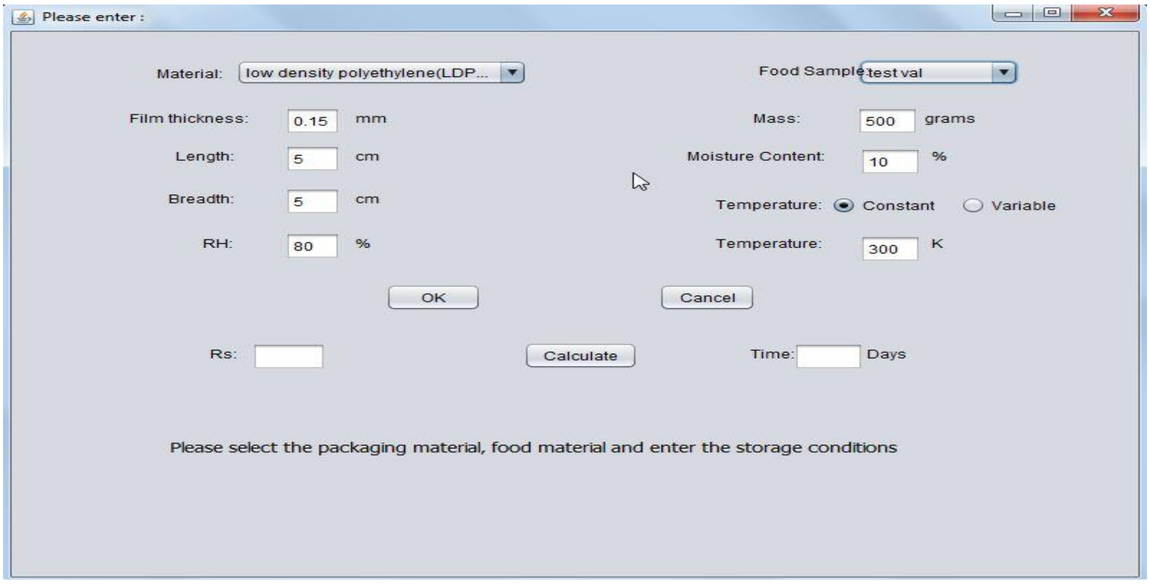
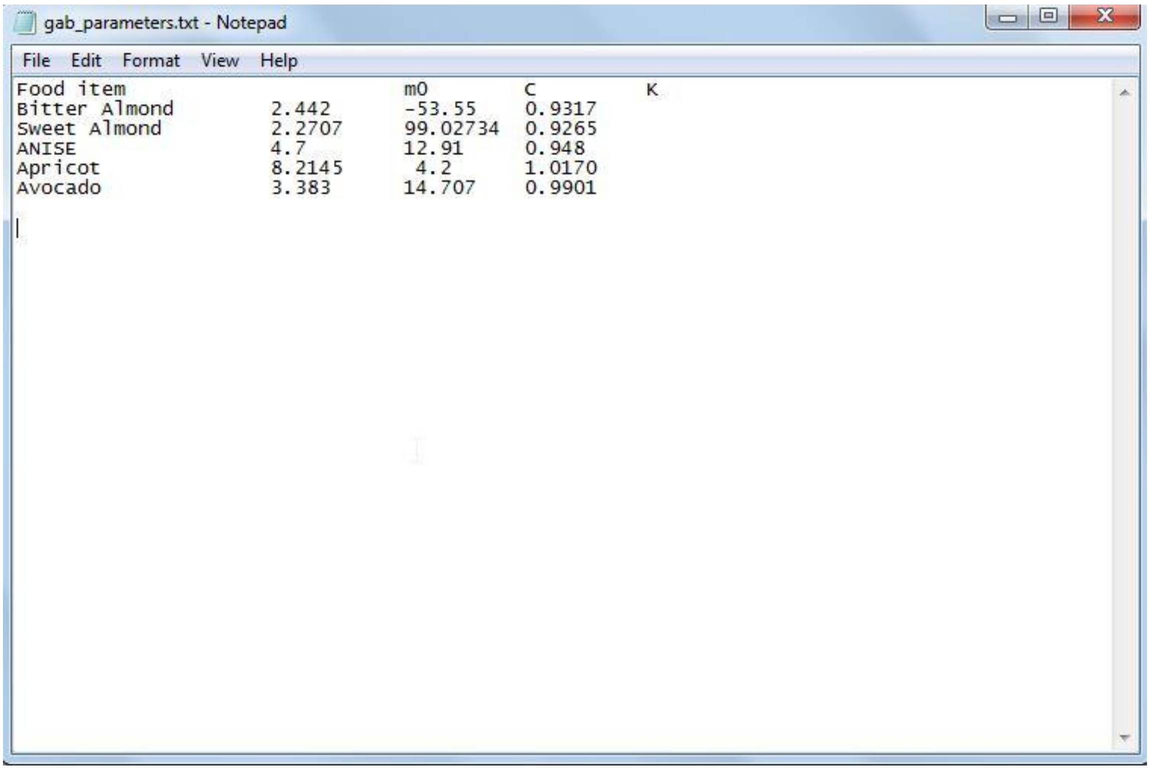


Figure 4.3. Interface for entering the storage conditions, packaging material and food

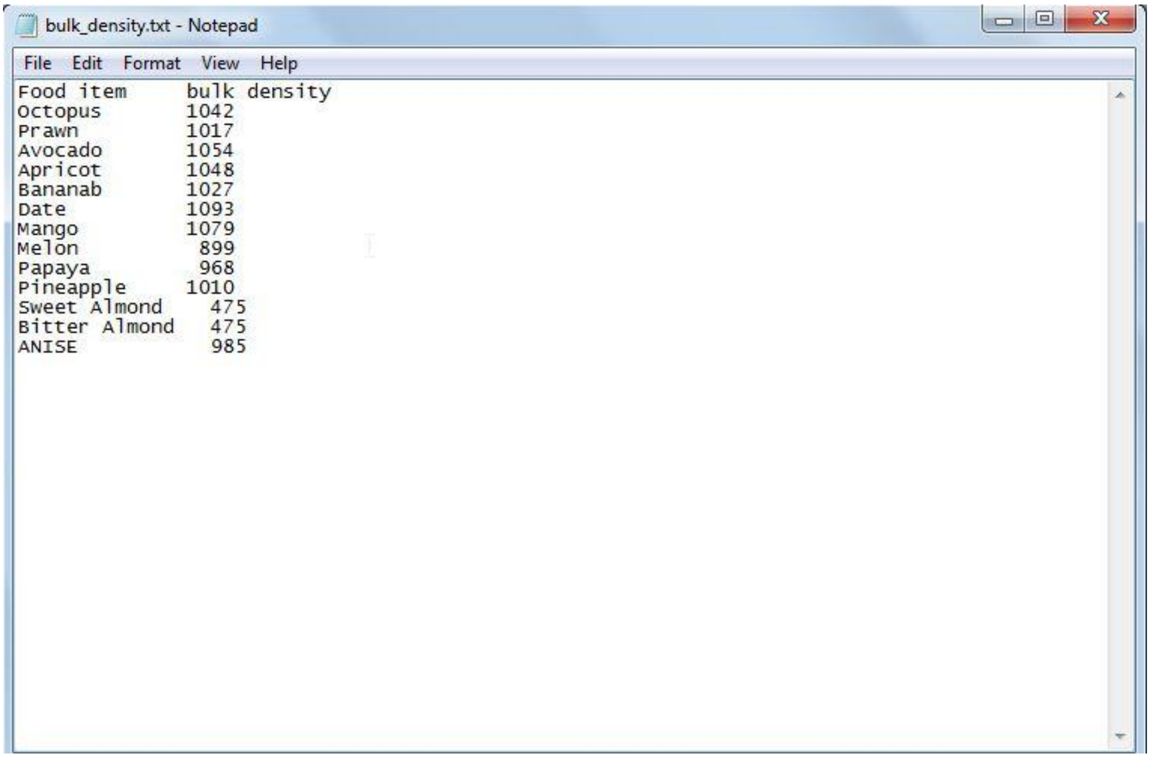
Material


gab_parameters.txt - Notepad

File Edit Format View Help

Food item		m0	C	K
Bitter Almond	2.442	-53.55	0.9317	
Sweet Almond	2.2707	99.02734	0.9265	
ANISE	4.7	12.91	0.948	
Apricot	8.2145	4.2	1.0170	
Avocado	3.383	14.707	0.9901	

Figure 4.4. Gab parameters database before running ‘Inter-pak’


bulk_density.txt - Notepad

File Edit Format View Help

Food item	bulk density
Octopus	1042
Prawn	1017
Avocado	1054
Apricot	1048
Bananab	1027
Date	1093
Mango	1079
Melon	899
Papaya	968
Pineapple	1010
Sweet Almond	475
Bitter Almond	475
ANISE	985

Figure 4.5. Bulk density of food material database before running ‘Inter-pak’

Frame 4 Pop-up box for food material and the values entered

This frame shows the values entered by the user in the pop-up box

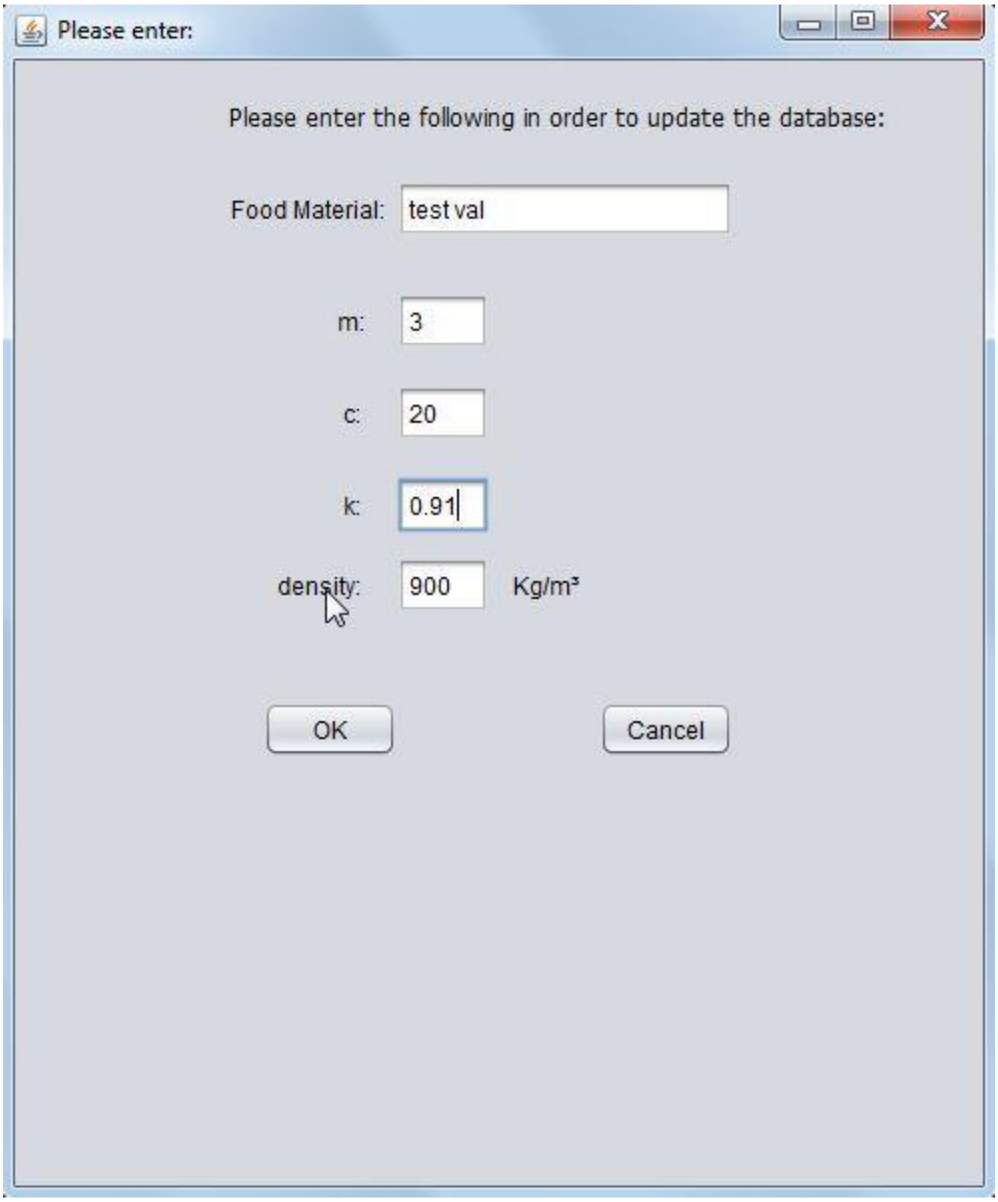
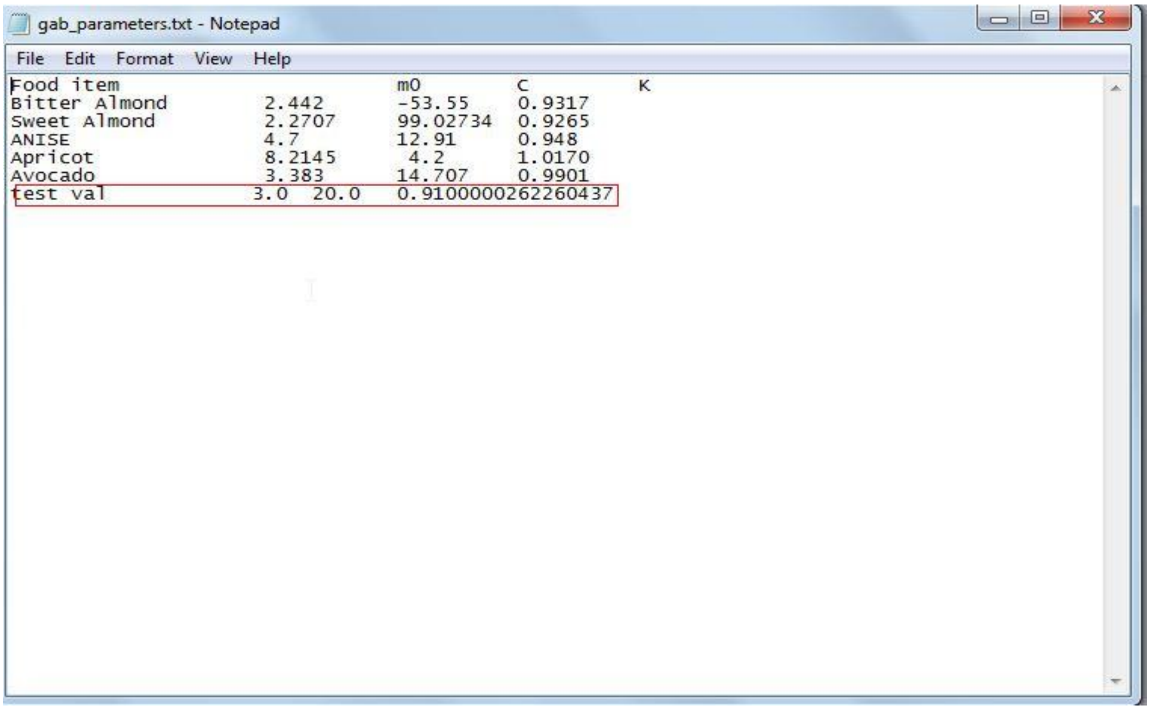
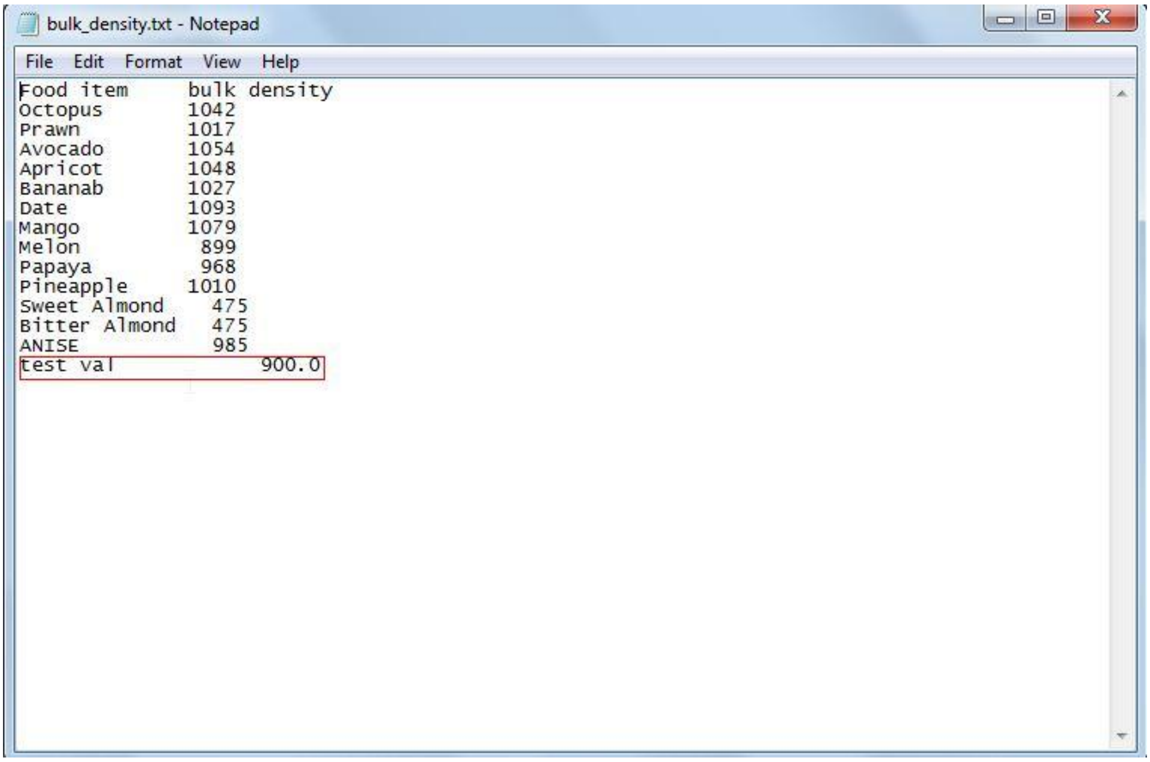


Figure 4.6. Pop-up box for food material and the values entered



```
Food item                  m0         C          K
Bitter Almond        2.442      -53.55     0.9317
Sweet Almond         2.2707     99.02734   0.9265
ANISE                4.7        12.91      0.948
Apricot              8.2145      4.2       1.0170
Avocado              3.383      14.707     0.9901
test val            3.0  20.0   0.910000262260437
```

Figure 4.7. Gab parameters database after running ‘Inter-pak’ (with the given values)



```
Food item      bulk density
Octopus        1042
Prawn          1017
Avocado        1054
Apricot        1048
Bananab        1027
Date           1093
Mango          1079
Melon           899
Papaya          968
Pineapple      1010
Sweet Almond     475
Bitter Almond    475
ANISE            985
test val             900.0
```

Figure 4.8. Bulk density database after running ‘Inter-pak’

4.2.2 Updating Packaging Material Database

Frame 1 Choosing the packaging material (whose data is not in the database)

This frame shows the packaging material chosen by the user from the drop down menu

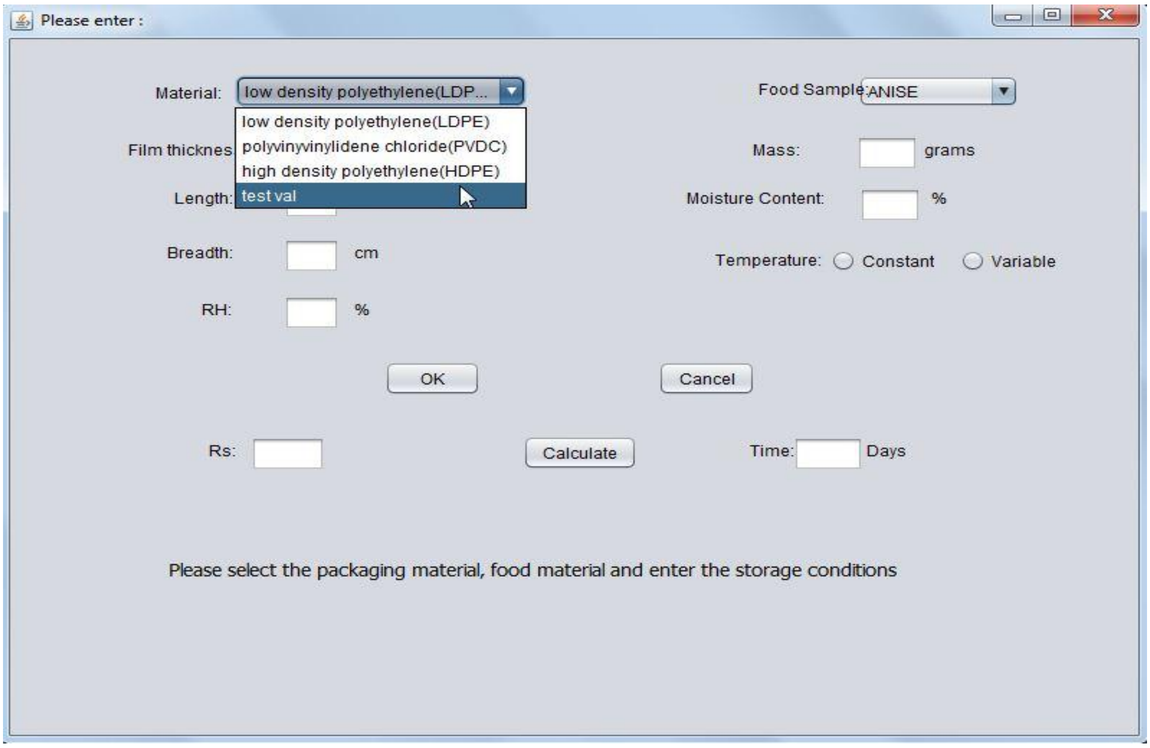


Figure 4.9. Choosing the packaging material (whose data is not in the database)

Frame 2 Choosing the food material

This frame shows the user selecting the food material

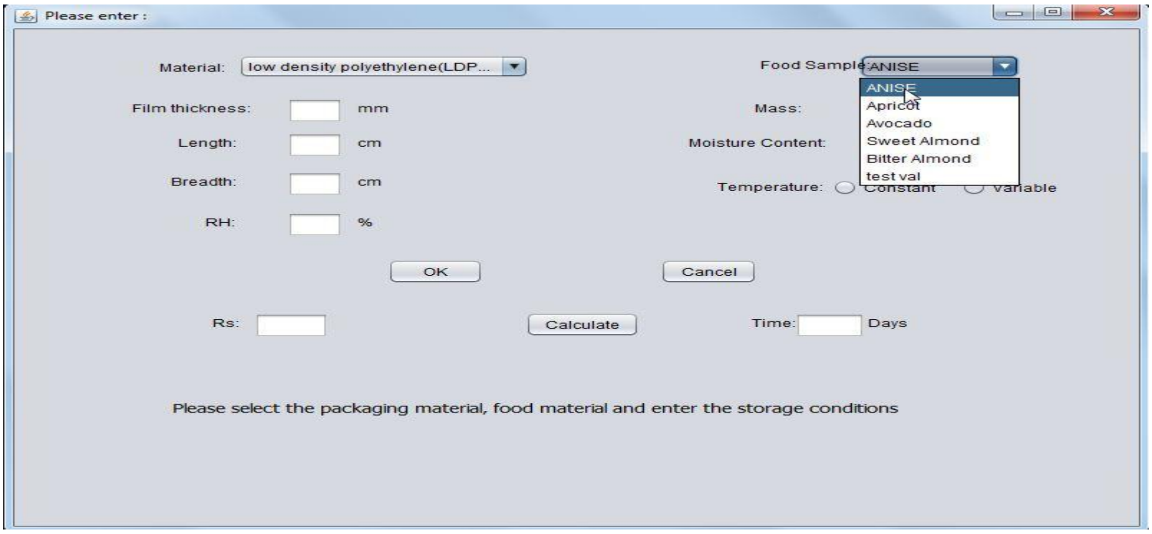


Figure 4.10. Choosing the food material

Frame 3 Interface for entering the storage conditions, packaging material and food Material

The interface asking the user to enter the storage conditions, choose the packaging material, the food material and other inputs required

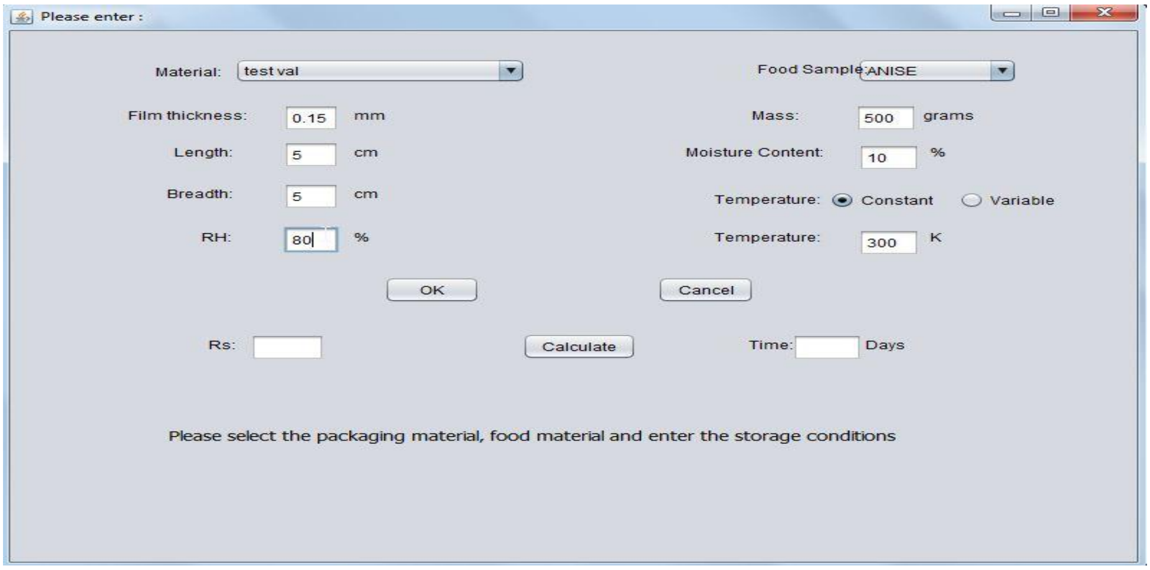


Figure 4.11. Interface for entering the storage conditions, packaging material and food

Material

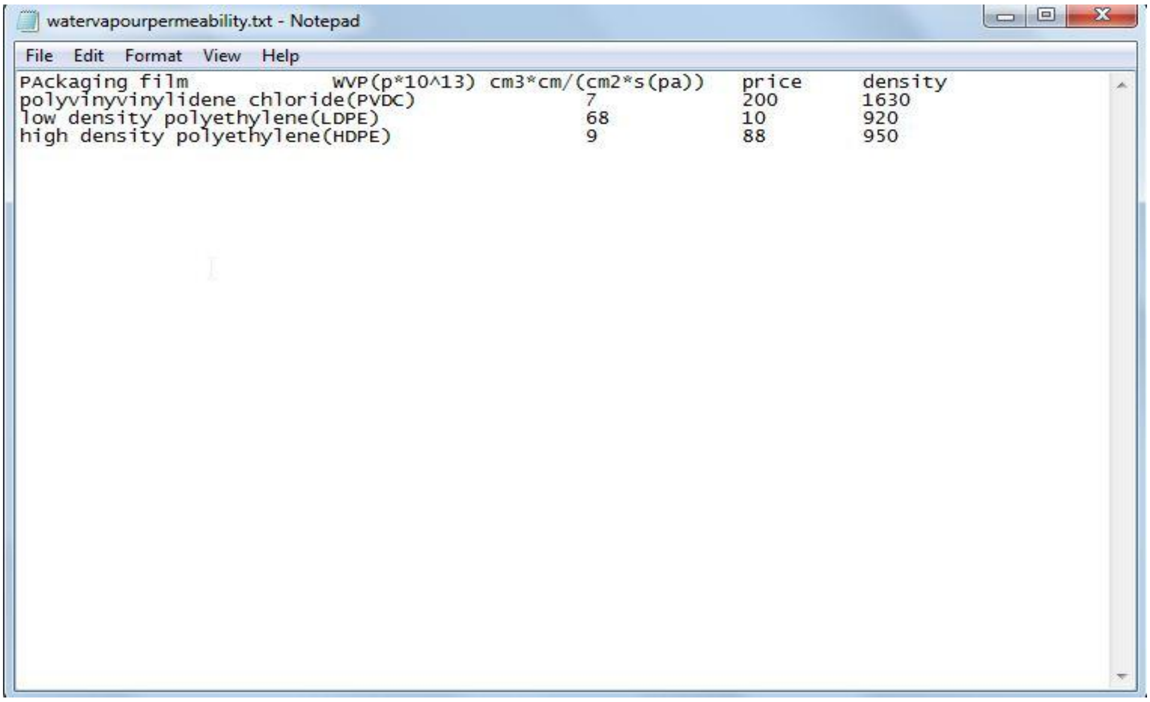


Figure 4.12. Permeability database before running ‘Inter-pak’

Frame 3 Pop-up box for packaging material and the values entered

This frame shows the pop-up box and the values entered by the user

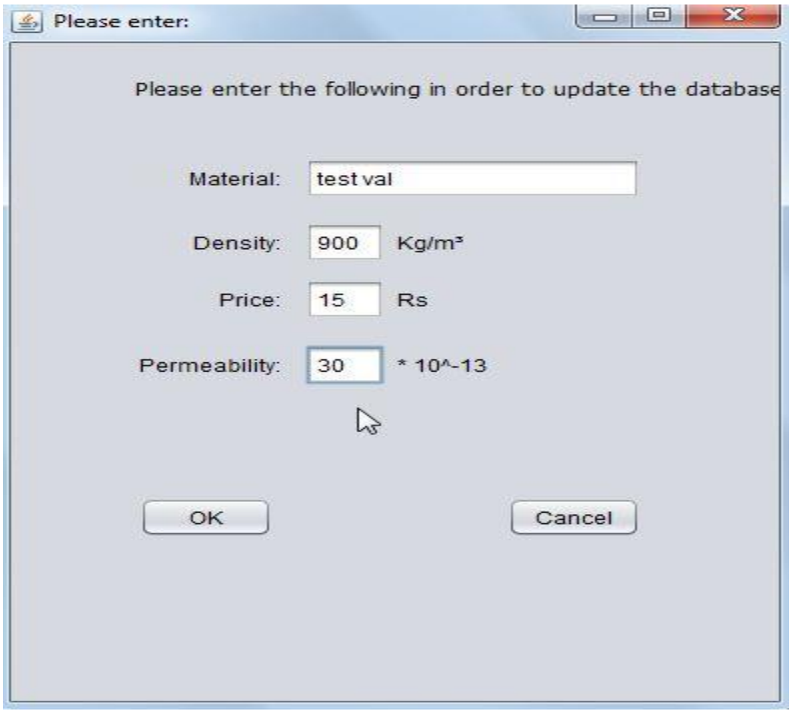
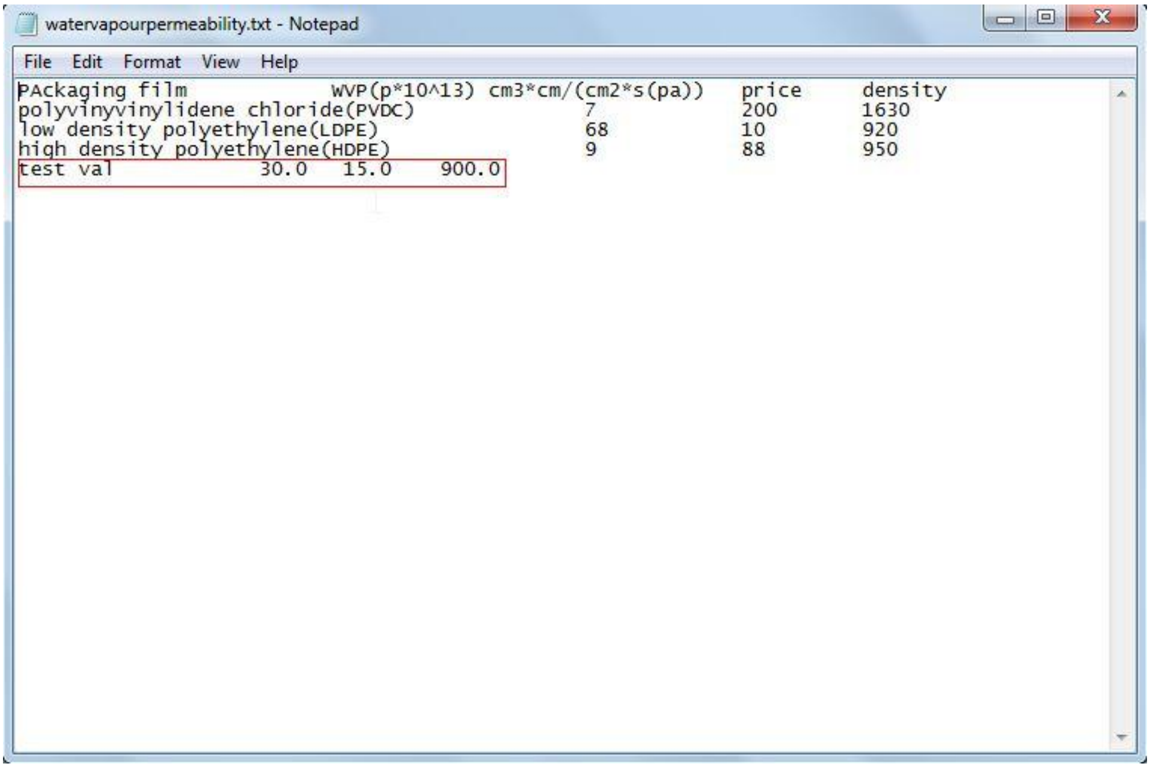


Figure 4.13. Pop-up box for packaging material and the values entered



watervapourpermeability.txt - Notepad

File Edit Format View Help

```
PAckaging film            WVP(p*10^13) cm3*cm/(cm2*s(pa))    price      density
polyvinyvinylidene chloride(PVDC)               7            200        1630
low density polyethylene(LDPE)                  68           10         920
high density polyethylene(HDPE)                 9            88         950
test val            30.0    15.0     900.0
```

Figure 4.14. Permeability material database after running ‘Inter-pak’

4.2.3 Test Case With All Options

Frame 1 Choosing the packaging material

This frame shows the packaging material chosen by the user from the drop down menu

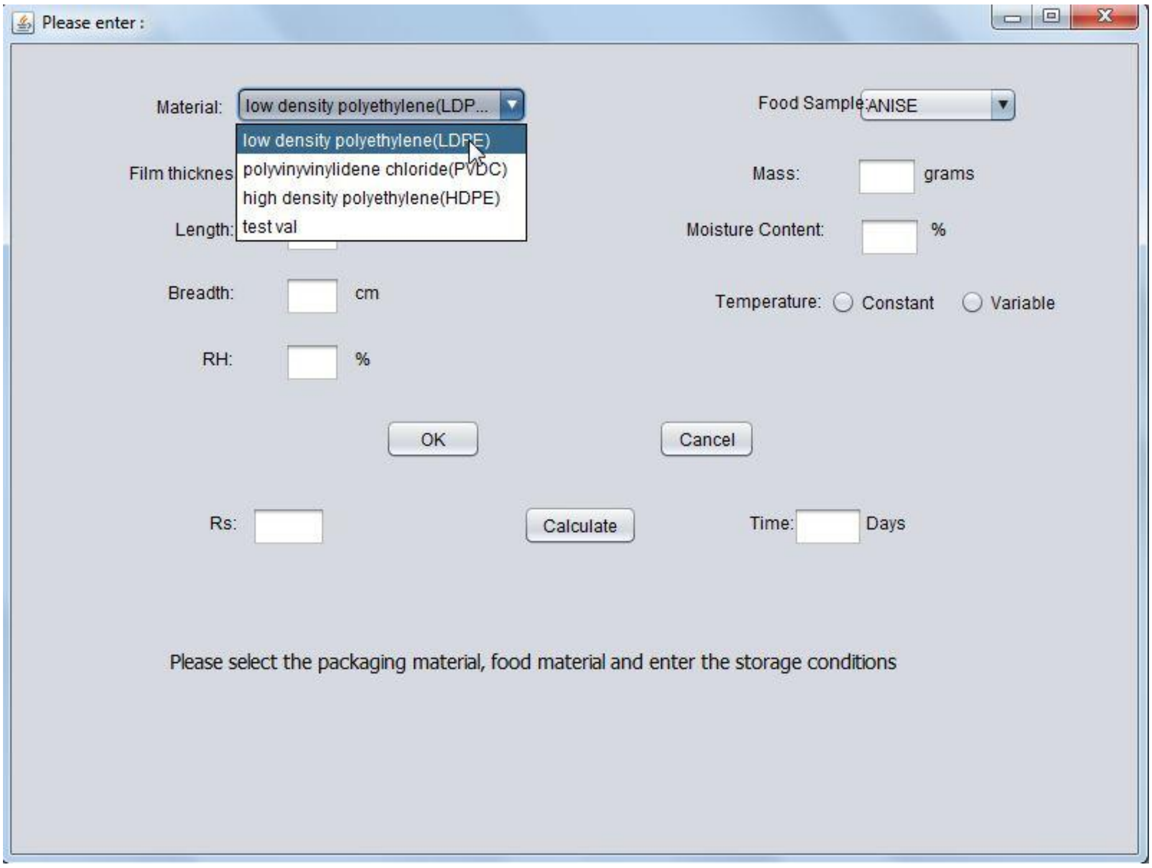


Figure 4.15. Choosing the packaging material

Frame 2 Choosing the food material

This frame shows the food material chosen by the user from the drop down menu

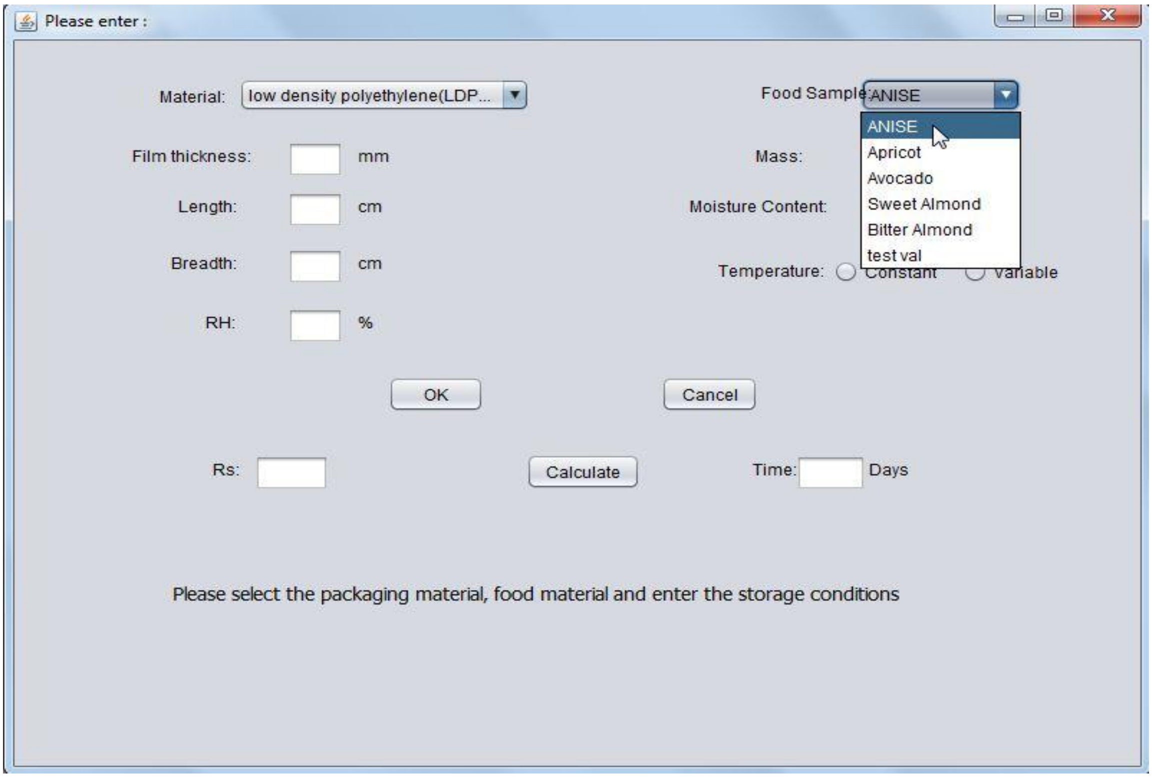


Figure 4.16. Choosing the food material

Frame 3 The storage conditions, packaging material and food material

This frame shows the storage condition, packaging material and food material values entered by the user

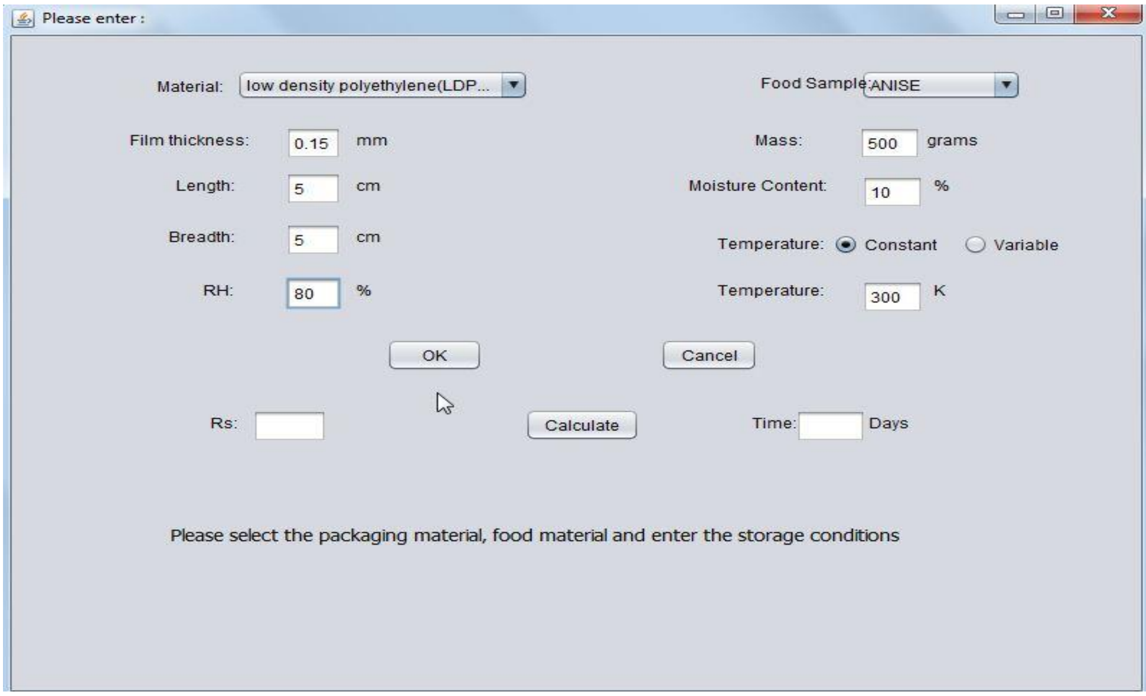


Figure 4.17. The storage conditions, packaging material and food material

Frame 2 The shelf life and cost of packaging under those conditions

This box-up box allows tells the user the calculated shelf life and the cost of packaging.

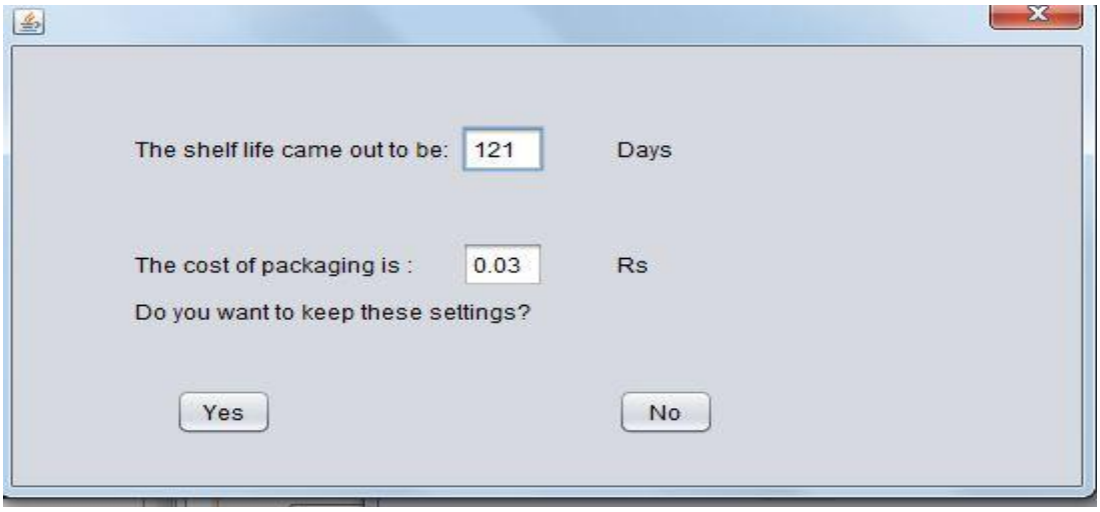


Figure 4.18. The shelf life and cost of packaging under those conditions

Frame 3 Pop-up box if user does not want the shelf life/cost as calculated

This pop-up box allows user to choose what changes he would like to make. The options are changing thickness or adding more layers.

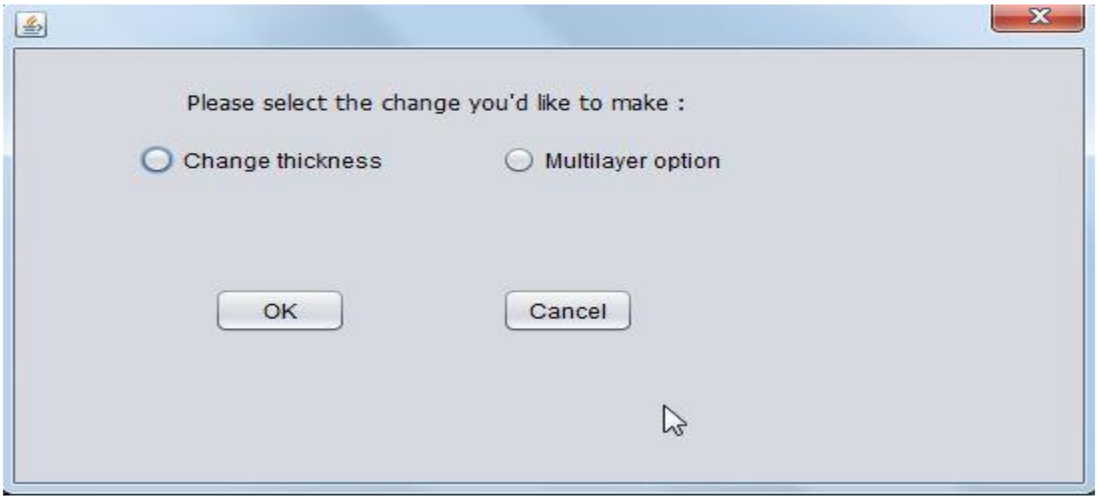


Figure 4.19. Pop-up box if user does not want the shelf life/cost as calculated

Frame 4 Option for changing thickness

The pop-up box allows the user to change the thickness of the packaging material

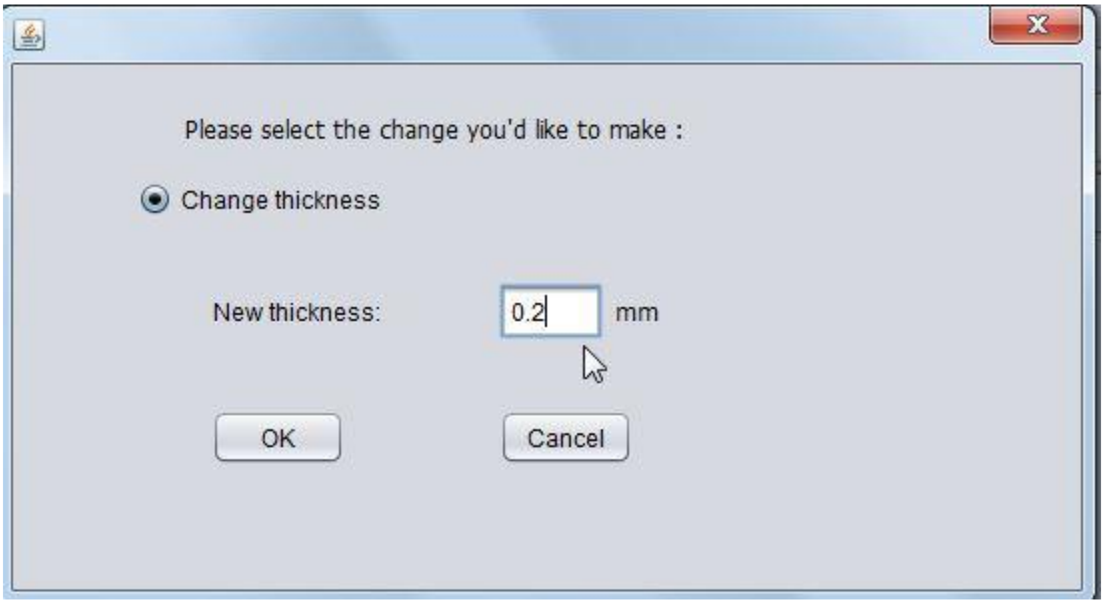


Figure 4.20: Option for changing thickness

Frame 5 The new shelf life and cost of packaging

The pop-up box shows the user the calculated shelf life and the cost of packaging and asks the user if he/she wants to keep these settings.

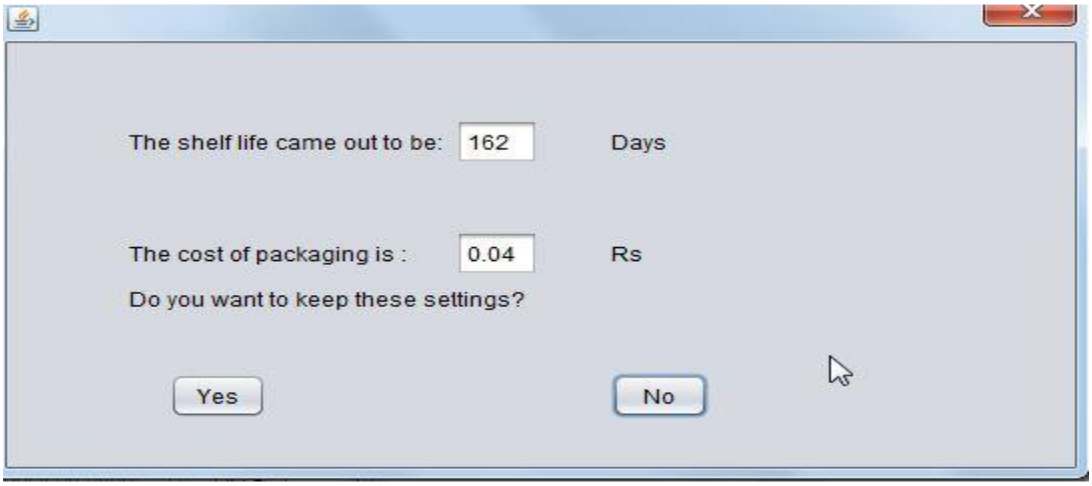


Figure 4.21. The new shelf life and cost of packaging

Frame 6 Choosing two layers of packaging

This frame allows the user to choose more than one layer of packaging and enter the thickness for multilayer option

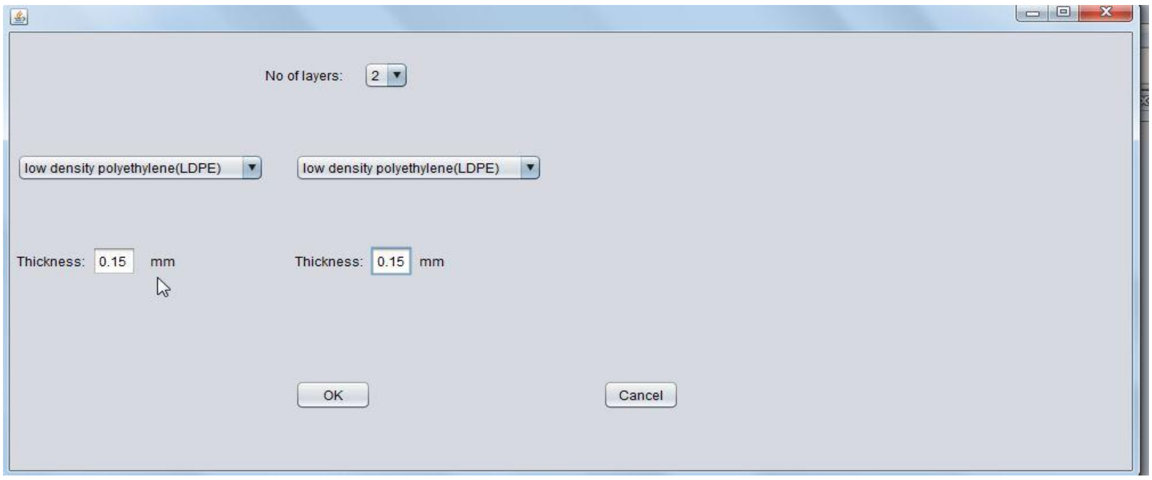


Figure 4.22. Choosing two layers of packaging

Frame 7 Choosing two layers of packaging

This pop-up box shows the user the calculated shelf life and the the cost of packaging on choosing two layers of packaging.

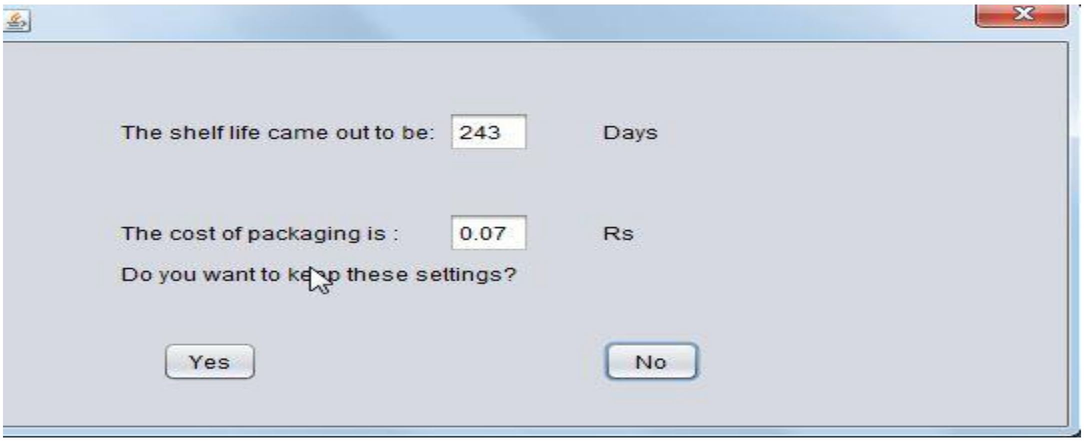


Figure 4.23. The new shelf life/cost of packaging on choosing 2 layers of packaging

Frame 8 Pop-up box for variable temperature

This pop-up box allows the user to enter the mean, maximum and minimum temperatures so that the program can calculate the hourly temperature.

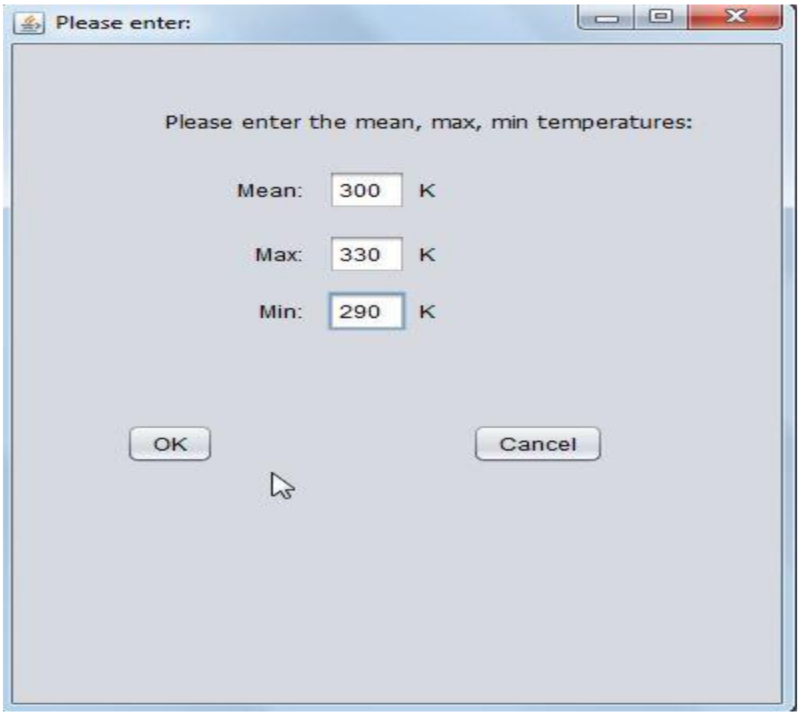


Figure 4.24. Pop-up box for variable temperature

Frame 9 Output with variation of temperature option

This frame shows the output shelf life and cost of packaging using variable temperature option

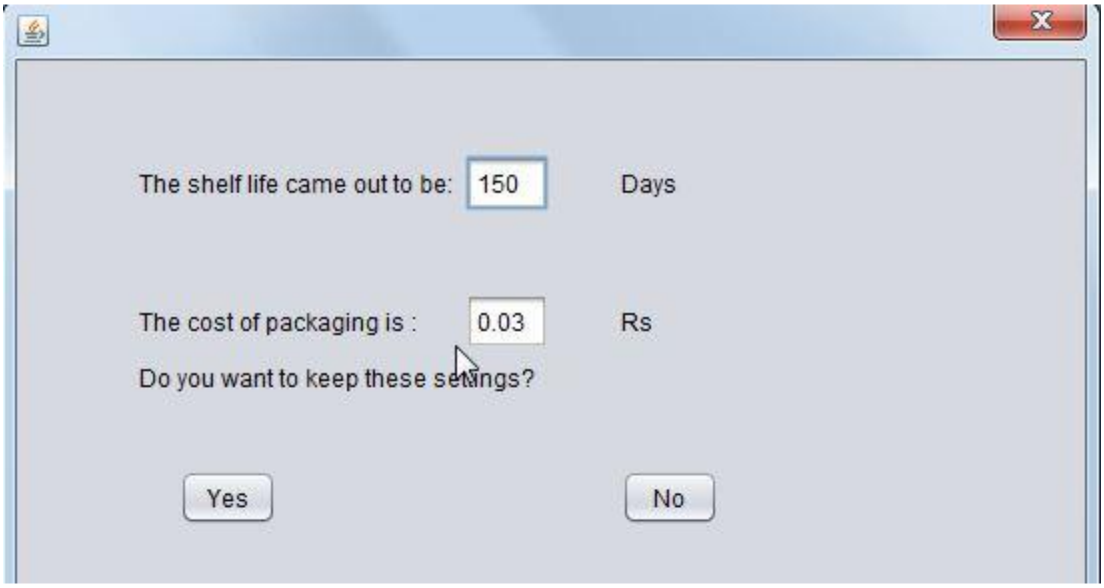


Figure 4.25. Output with variation of temperature option

4.3 Discussion

'Inter-pak' gives reasonable results with some values but gives absurd results with some others when the relative humidity is too low. This is because for lowvalues of relative humiditythe pressure difference is small and the iteration converges to a constant value of water activity(a_w) before the limit is reached. Hence we get an infinite loop. So, it will take a long time to reach water activity of 0.6.

Also for high values of moisture content we het time of storage as zero because 'Inter-pak' calculates the water activity value to be already greater than 0.6. In this case the food material should be further dried before packaging.

The user has the option of choosing a constant temperature. Having a variable temperature having pulse variation is closer to the temperature fluctuation during the day.

CHAPTER 5:CONCLUSIONS

5.1Conclusions

- The calculation of storage time using Gab model is useful in some cases. Generally it provides a good description of the sorption behaviour of most food items. But the Gab model is unsuitable for high humidity values.
- We note that the storage conditions have a major impact on the shelf life of a food material. Also the choice of packaging material and number of layers also affect the shelf life.
- The triangular pulse variation should be used to model the variation of temperature during the day as it is more accurate.

REFERENCES

1. Blahovec J., Yanniotis S.(2010), 'Gab' generalised equation as abasisfor sorption spectral analysis. Czech J. Food Sci., 28:345-354.

2. Richard C., McDowell D., 'Food Packaging Technology'(2003), cRc press, Blackwell Publishing.

3. CRCnetBASE – Handbook of food properties, Second edition http://www.crcnetbase.com/isbn/978-0-8493-5005-4

4.Prothon F., Ahrne L.M., 'Application of the Guggenheim, Anderson and De Boer model to correlate water activity and moisture content during osmotic dehydration of apples' , Journal of Food Engineering 61 (2004) 467–470

5. Geankoplis C. J. 'Transport Processes and Unit Operations',Third Edition(1993), Prentice Hall International

6.Wypych G., Handbook Of polymers(2012) , Chem tree Publishing Toronto

APPENDIX A - NOTATION

Symbol	Meaning and unit
a_w	Water activity, dimensionless
D_{AB}	Diffusivity of A in B, m^2/s
L_i	Thickness of ith layer
m_0 , c, k	GAB model constants
M	kmol of water diffused in that time
m_{add}	moisture added, % db
M_0	Monolayer sorbate content (kg water/kg dry matter)
N_A	Flux of A, $kmol/\, m^2 s$
P_{AB}	Water vapour permeability of packaging material, m^3(STP) mm/ Pa m^2s
P_i	Water vapour permeability of ith layer, m^3(STP) mm/ Pa m^2s
P_{inside}	Vapour pressure of water inside the packaging layer (inside the food material), kPa
P_0	Saturated vapour pressure at temperature T, kPa
$P_{outside}$	Vapour pressure of water outside the packaging layer, kPa
r.h	Relative humidity, %
S	Solubility m^3(STP)/m^3 solid Pa
T	Temperature, K
z	Thickness of the packaging material