Handbook for measuring respiration and how to determine the needed permeability in a packging film for optimum shelf-life of any fresh produce (salad, vegetables and fruit) and Flowers.

Denmark – January 2021

Revision 2021-3

Forword:

This handbook is to describe one of the important factors in establishing the best possible conditions for optimum shelf-life of produce like salad, vegetables and fruit – the interaction between respiration and permeability and how to measure and calculate the different factors are explained in an easy-to-understand steps.

With this handbook our goal is to simplify steps to measure respiration and also explain the use of the website in calculating the optimum permeability of a packaging film whereby the permeability of the film is adjusted by means of laser perforation.

DANFRESH

Contents:

Preparation for measuring respiration

For measuring respiration, you will need different equipment, which are described in the following pages.

1.1 Scale for weighing

The scale can be a household scale, but it must have an accuracy of 1 gram or less. It must also have a weighing capacity of a minimum of 1000 gram and a maximum weighing capacity of 1500 grams.

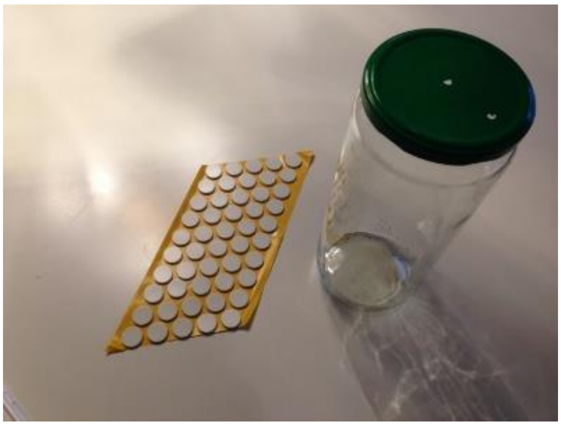
1.2 Jar with lid

In our shop on the website you can order the jars we recommend for measuring respiration. There are different important issues to be aware of:

- It must be 100 % airtight, this is absolutely important!!
- It must have a lid that is screwed on top of the jar
- We recommend to have a minimum of 3 jars for each product you want to test at a time for better accuracy or results
- We recommend a height of minimum 20 cm / 10 inches and an opening in the top with a diameter of minimum 70 mm / 3 inches. For large whole fruits, a different jar may be needed with wider opening
- Calculate or measure the inner volume of the jar in ml or cc

If you buy the jars from our website, then the hole in the lid is already made, but if you use jars of your own, then you must drill one or two small holes. We use a size of 4 – 6 mm in diameter. For use in combination with a Mocon Checkpoint you need only one hole.

When you use the jars for measuring, you can cover the hole with septums (part number PBI-310336 from Mocon).



Next step is to find the exact volume of your jar. You can do this by weighing your jar with lid.

You will need the following items:

- Scale
- Water from tap

Volume can be measured by filling tap water into the jar to the top and then weigh the amount of water (Need the net weight of water)

Since density of water is 1, weight of water is equal to the volume of the jar.

Label the jars so it is easier to mark them with product filled, weight filled and the date and time the respiration test is started

1.3 Thermometer

Temperature is an important factor when you measure respiration. The respiration study should be done at the same temperature at which the product is displayed in the retail environment (this is the longest amount of time the product stays at). You can measure the temperature using any device as long as it displays the temperature accurately although we use the infrared thermometer as shown below.

The infra-red thermometer can be purchased in shops for about 30 USD and up, a higher price often gives more accuracy.

1.4 Equipment for measuring O2 and CO2 - Checkmate

The best equipment available on the market is the Checkmate 3 from Ametek Mocon, this unit offers a very good accuracy, and it has all the necessary functions for exact and automatic measuring of O2 and CO2

This picture to the right shows the complete set-up.

Please note the transparent hose which goes from the side of the Checkmate to the needle into the lid of the jar. This is the sampling needle/hose.

From the back of the Checkmate you must connect the other hose to the exhaust port of the Checkmate (here we have used a black hose). Now you have created a closed loop which allows to take a sample of gas for analysis from the sample needle and after analyzing the measured gas is being purged back into the jar. With this procedure you can make sure neither vacuum nor overpressure is created in the jar. In case of vacuum or overpressure you will see an error message in the display: error code 601:

In case of this error message, check for blockage in the flow system. Check the hoses and filters and start again.

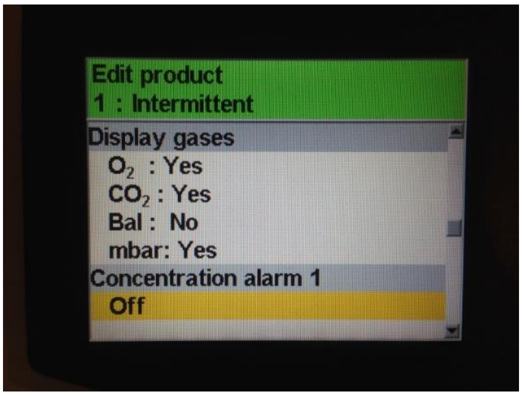
It is recommended to change the septums before you start a new test.

To make an automatic test with the Checkmate you need to set up a program in the settings of the Checkmate, please refer to the Checkmate manual for this.

If you need to make a new product or modify an existing one, the following settings are recommended:

Sample time:	10.0 sec
Delay:	240 min
O2:	yes
CO2:	yes

Screen shots of settings:



Screenshots of settings:

Please remember to save the new settings in the Checkmate. For any questions about setting up the Checkmate, please refer to the Checkmate manual.

1.5 Equipment for measuring O2 and CO2 – Checkpoint 3

We recommend the use of the Checkmate from Ametek Mocon, as it has all the functions you will need for measuring O2 and CO2 in an automatic set-up. But you can also use the Checkpoint 3 from Ametec Mocon, this unit gives you the basic functions of measuring O2 and CO2 but only in a manual measuring mode.

The Checkpoint 3 unit only has the gas sampling function, it is not able to purge the analyzed gas back to the jar, therefore it is not recommended to make the gas sampling more often than every 4 or 8 hours. The reason for this is to avoid creating any vacuum in the jar every time you measure gas values. The Checkpoint 3 takes about 5 ml of gas during a test.

2.1 Acclimatization of the product and the jar

The first thing to do is to acclimatize the product you want to measure. In the example we have chosen carrots. In order to acclimatize your product, keep your product in the same temperature as the testing temperature for **minimum 2 hours**, this will secure that your product is in a good temperature balance and is fully acclimatized.

2.2 Measuring steady state (equilibrium) in your commercial bags/packaging

We recommend you should also test some commercial bags with the same product you are about to run the respiration study for. The best approach is to take the bags directly from the packing line. Keep these commercial bags at the same temperature as your testing jars with product inside. You should measure the level of O2 and CO2 through the lifetime of your product. If freshly packaged product is not available, get the same product from the market and measure the oxygen/CO2. Code date should give some idea of the age of the product so you can relate the oxygen to a given day in the age of the product.

Typical example of data from measuring O2 and CO2 in a commercial bag (Picked up from freshly packaged product from the commercial packing line) in 8 days:

Hours measuring	0	4	12	24	48	96	144	192
O2 measured	20,90	19,40	17,10	14,70	12,10	11,50	11,45	11,45
CO2 measured	0,00	1,60	3,90	6,30	8,90	9,50	9,55	9,55

In the example above, we notice that in about 48 - 192 hours the O2 and CO2 values becomes stable (Do not change much). This is called Steady State or equilibrium state which means that the product is balance with the packaging. This balance can be met at different levels of O2 and CO2. It will depend on the product and the packaging and also the number of micro holes (laser perforations) in the packaging. If your packaging has many holes then the level of O2 and CO2 with stabilize at a high level of O2, and if your packaging has few holes then it will stabilize at a lower level (steady state).

To find the Steady State of your commercial bags is very important, as this information is a necessary information for optimizing the packaging which we will focus on in a later chapter.

2.3 Measuring respiration

We recommend filling the jar with enough product. This means that you should fill the jar with enough product to leave minimum 10 mm headspace from the top of the jar. If you have a lightweight product like spinach or leafy greens you can put a little pressure on your product to fill the jar to its maximum. Idea is to minimize air spaces between the product.

If you don’t fill the jar to its maximum then the ratio between jar volume and product wight will be too low, and it will have the negative impact in that the testing will take longer time. On the other hand, if you fill the jar with little extra product, then you will speed up the test and reduce the testing time.

Remember also always to acclimatize the jar and lid before filling the jars with product, and always keep the filled jars at controlled testing temperature during storage. Only remove from the controlled temperature for measuring the O2 and CO2 or better take the readings inside the cooler (If a walk-in cooler).

After the acclimatization period you can put your product in the jar and close the lid and make sure that the lid is tightened carefully.

There are no fixed rules for the length of the time you need to measure in a respiration study. It depends highly on the product being tested and on the temperature at which the product is being tested at.

It is recommended to measure the respiration at the same temperature as your commercial bags are mostly exposed to (Shelf temperature at the stores where your product is sold at).

As a guideline, we advise you should continue to measure the O_2 and CO_2 values of the product in the jars until your O_2 values are at least 5 % lower than the steady state value of O_2 measured in your commercial bags. But there can be some exception to this suggestion. For example, if the product has a high content of Iceberg lettuce where the desired level of O_2 is typically below 1 % O_2 then you should continue to measure levels of O_2 and CO_2 in the jars until you are close to 0 % O_2.

How often shall you measure the level of O_2 and CO_2 in the jars? You should be aware of the fact that every time you measure the gases in the jars with a Checkpoint 3, you take out a gas sample of about 5 ml, and as the jars are airtight, you create a vacuum inside the jar. However, in most cases you will have a miniscule leak around the septum and also every time you take the needle out from the septum a small amount of surrounding air will enter into the jar. Therefore, you should not make the measurements too often, try to do it only when its relevant. If you are using a Checkmate for measuring which has a closed loop/flow system then there will be no vacuum build up and with this system you can measure as often as you like.

As a guideline on measuring interval in the jars, you shout have a decrease in O_2 from closing the lid till the first measuring of minimum 1 % O_2, but not more than about 3 % O_2. It can in principle be anytime from 30 minutes till some hours, that depends on product and temperature. The second measurement could be after 2 hours-4 hours depending on the product type. That will of course need several measurements to find the ideal testing interval:

A suggestion could be the following measuring schedule:

Time	action	hours in test
08:00 AM	closing the lid	0 hours
10:00 AM	1 measurement	2 hours
16:00 PM	2 measurement	6 hours
08:00 AM	3 measurement	24 hours
08:00 AM	4 measurement	48 hours
08:00 AM	5 measurement	72 hours
08:00 AM	6 measurement	96 hours

But as said its just a guideline, you have to test and try to find the best timing for your product and temperature.

In the member section on the website you can find a respiration chart without data for download. Its recommended to print and use this on paper when you manually fill in your measuring data during the resting. When your test is finished you can fill in the data to the chart on the website and read the results.

Example of respiration chart without data for printing:

Product:		**Glass volume:**	ml
Sort:		**Product weight:**	g
Origin:		**Product density:**	g/ml
Measuring jar no:		**Headspace:**	ml
		Temperature:	C or F

	Time:							
O2	**Hours measured:**							
O2 measured	20,90							
O2 respiration rate in "ml O2 kg/hr"								

CO2								
CO2 measured	0,00							
CO2 respiration rate in "ml CO2 kg/hr"								
RQ (RRCO2/RRO2)								

Temperature at measuring time:							

Bag measurements:		
Headspace gas measurement in the bag before opening:	**O2**	**CO2**
Measured at time:		
Measured at temperature:		

Jar measurements:	
Steady State EMAP O2 in the bag:	
Respiration Rate at steady state:	
Anerob condition below:	

Its recommended to fill in all the requested data

2.4 Understanding the measured data

When you have filled all data into the paper version of the respiration chart, you can login into the website and fill in the data on the online chart.

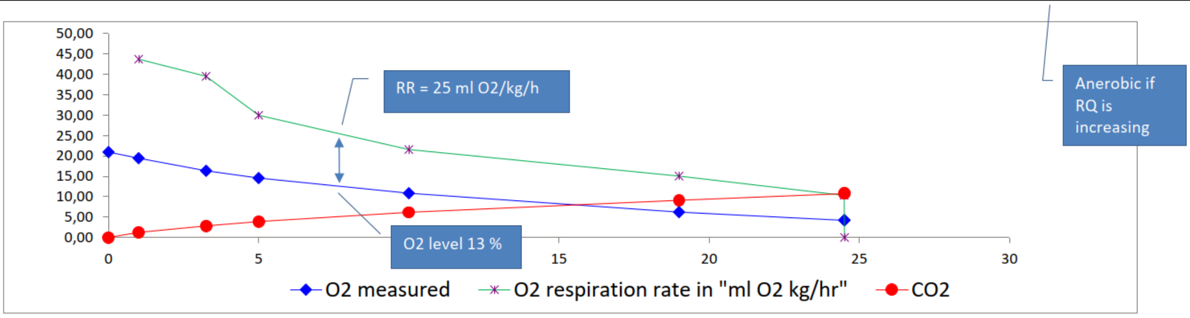
Example:

Product:	Broccoli sliced for vokmix	**Jar volume:**	1056 ml
Sort:		**Product weight:**	270 g
Origin:		**Product density:**	1 g/ml
Measuring jar no:	10 + 15 average	**Headspace:**	786,0 ml
		Temperature C or F:	7 C

Time	13:00	14:00	16:15			08:00	13:30	
Hours measuring	0	1	3,25			19	24,5	24,51
O2 measured	20,90	19,40	16,35			6,20	4,25	4,25
O2 respiration rate in "ml O2 kg/hr"		**43,67**	**39,46**	**29,94**	**21,54**	**15,04**	**10,32**	**0,00**

Level of respiration

CO2								
Hours measuring	0	1	3,25	5	10	19	24,5	24,51
CO2 measured	0,00	1,25	2,85	3,90	6,15	9,10	10,80	10,80
CO2 respiration rate in "ml CO2 kg/hr"		**36,4**	**20,7**	**17,5**	**13,1**	**9,5**	**9,0**	**0,0**
RQ (RRCO2/RRO2)		0,8	0,5	0,6	0,6	0,6	0,9	



Steady state EMAP O2 level in the bag	13 % O2
Respiration Rate	25 ml O2/kg
Anerob below	6 % O2

Many product information's can be read from the chart.

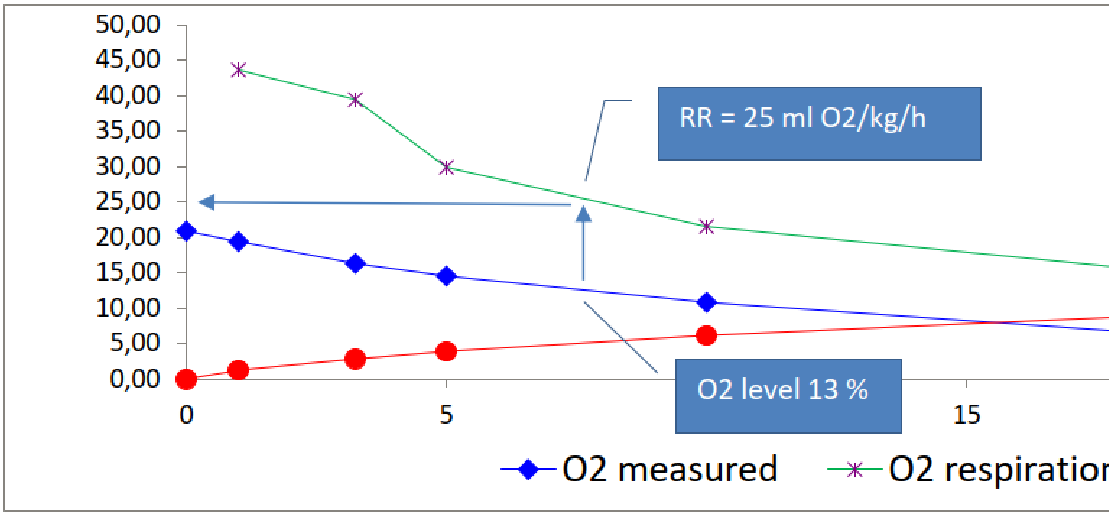
1. Level of respiration: All the data in the line "O2 respiration rate in ml O2 kg/hour" refers to an actual Respirate Rate (RR). But note that level of respiration decreases when the level of O2 decreases in the jar. In the example above, the level of O2 has decreased after 24.5 hours from the start from 20.9 % to 4.25 % and at **19.4 %** O2 the product has an RR of 43.67 ml O2 kg/hr. At an O2 level of 4.25 % the RR is only 10.32 ml O2 kg/hr.

   As you can see the RR decreases with the decrease in available oxygen in the jar.

   By reducing the level of respiration, you will increase product quality and increasing product shelf life.

2. What is the actual RR for your product? To find the actual RR for your product you should make the complete respiration test as described above. Next step is to make and understand the following:

Copy from the chart:



Start finding the blue line for the measurements of O2, its starts at the value of 20,9 % O2 and decreases with each of your measurements. Now you must find the Steady State value of O2 you have measured in your commercial bag, you should by now have noted this in the paper chart:

Jar measurements:

Steady State EMAP O2 in the bag:	**13 %**
Respiration Rate at steady state:	
Anerob condition below:	

Now go back to the blue line in the respiration chart above and find the point on the line for 13%. Its marked with a "blue text box". From that point you can make an imaginary vertical line up to the green line (the green line indicates the values of respiration)

In this case you can read on the chart that the RR is 25 ml O2 kg/hr and fill that in the paper

Jar measurements:

Steady State EMAP O2 in the bag:	**13 %**
Respiration Rate at steady state:	**25 ml O2 kg/hr**
Anerob condition below:	

3. From the chart above you can also see the RQ (respiration coefficient):

RQ (RRCO2/RRO2)	0,8	0,5	0,6	0,6	0,6	0,9	

When the values are decreasing or stable, it means that the product is respiring aerobic, which is good, but when its starts to increase then it's a sign that the product is going into an anaerobic state which is undesired. To read this from the chart, you can do the following:

2.

	14:00	16:15	18:00	23:00	08:00	13:30	
Hours measuring	1	3,25	5	10	19	24,5	24,51
O2 measured	19,40	16,35	14,55	10,85	6,20	4,25	4,25
O2 respiration rate	**43,67**	**39,46**	**29,94**	**21,54**	**15,04**	**10,32**	**0,00**

CO2

Hours measuring	1	3,25	5	10	19	24,5	24,51
CO2 measured	1,25	2,85	3,90	6,15	9,10	10,80	10,80
CO2 respiration rat	**36,4**	**20,7**	**17,5**	**13,1**	**9,5**	**9,0**	**0,0**
RQ (RRCO2/RRO2)	0,8	0,5	0,6	0,6	0,6	0,9	

Find the values where the RQ starts to increase, pos 1: 1.

Here the RQ starts to increase

Then go to pos 2 above

From pos 2. You can see the corresponding level of O2, here its 6,2 and 4,25. This means that the anaerobic state occurs somewhere between these values. You cannot from these values determine the exact value, we can estimate this to be close to 5,25 (the mean value).

Now you can fill the last information in the paper chart:

Jar measurements:

Steady State EMAP O2 in the bag:	**13 %**
Respiration Rate at steady state:	**25 ml O2 kg/hr**
Anerob condition below:	**5,22 %**

How to use this information for optimization. This can only be described in general terms as some products differs from others, therefore please see this as some rough guidelines.

There are three main facts:

1. For most products, anaerobic conditions in the packaging must be avoided
2. Temperature variations does have major impact on the respiration rate, higher temperature = higher respiration.
3. When respiration rates (RR) decreases = increase in product quality and shelf life

In the example above with sliced broccoli, we would suggest the following inputs for the packaging:

The optimum level of O2 in the bag at steady state is an O2 level just above the anaerobic level (5,22 % O2). But if the temperature changes (which it sometimes does, in all the logistic chain) this you should add a safety buffer to the O2 level. If the anaerobic level is at 5,22 % O2 then its recommended to add minimum 2 – 3 % O2 for safety. This means a level **lower level of about 8 %** O2 would be relevant. There is no real defined upper level, but as described above, as lower you keep the O2, the RR is reduced and product quality is increased, therefore an upper level about 5 higher, meaning **13 % O2 as upper level** can be recommended.

So now you have all the important data of your product and you can use this data in the simulation program on the website.

2.5 Measuring density

Please note, products can have different density which will have an influence on the respiration rate. Root crops are likely to have the same density where a default of 1.04 g/ml can be used for products like carrots, potatoes etc. For example, onions, has a lover density, typical around 0.98 g/ml.

Its easy to measure the density in the measuring jar in these simple steps.

1. **Find the volume of your jar**
    a. Place you jar and lid on the scale and press tara
    b. Fill the jar to the top with water
    c. Put the lid on the jar
    d. Fill the jar with water drops through the hole in the lid
    e. When the jar is completely full of water (you can see water in the hole of the lid, then you weigh the filled jar again

f. In my example the filled jar now weighs (jar + lid + water) 398 + 10 + 1100 = 1508 grams
g. Now take the total weight in grams minus the weight of the jar and the lid 1508 – 398 – 10 = 1100 ml. So the volume of the jar is 1100 ml

2. Measure the density of your product

a. Place the empty jar on the scale
b. Put your product into the jar
c. Fill up with water to the top of the jar
d. Place the lid and fill with waterdrops through the hole in the lid until its full and you can see water in the hole.
e. Measure the weight of the jar (including the product and the water)

If you have filled the jar with for example 400 grams of carrots and filled up with water as described above, then your jar will now have a weight of about 1568 grams.

3. Calculate the density

Take the weight (including the carrots and water) 1568 grams and divide with the weight of the jar without the carrots but including the water 1508 grams

1568 / 1508 = 1.03978 or 1.04 g/ml

When you use the chart on our website you should modify the default density (1,04 g/ml) with the density you have measured.

4. Density examples

Product	**Density**
Carrots	1,02
Onion	0,97
Potatoes	1,03
Baby spinach	0,92
Broccoli	0,95
Iceberg	0,96

2.6 Measuring mixed products

If you are packing mixed products for example salad mixes, for measuring respiration you have two choices:

1. Measure the respiration on the exact mix you are packing
2. Measure the respiration of each individual product

Ad 1. This is the easy way to measure the respiration of a mix, we suggest that you take a sample from the commercial salad packing line and follow the procedure described above. But if you later want to change the content in mix, for example, change the percentage of cabbage from 30 to 50 % in the mix, then you have to make a new respiration test, in order to have true respiration information.

Ad 2. Instead, we suggest you measure each individual product in your mix, you could for example have the following products in your mix:

Green cabbage 65 percent

Radicchio 10 percent

Carrot sticks 10 percent

Cherry tomatoes 15 percent

We recommend you measure the respiration of each individual product at the same temperature for each product. When you have measured all your products, you can easily calculate the sum of respiration every time you change the content of your mix.

We have made a small and simple tool to help you with the calculation:

Calculation of respiration for mixed products

	Product	Temperature at measuring	Respiration rate - ml O2 kg/hr	Storage temperature of mix	Calculated respiration rate - ml O2 kg/hr	Percentage of product in the mix	Respiration rate per kg mix
Prooduct 1	Green cabbage	5	10	8	14,3	65	9,29
Prooduct 2	Radicchio	4	15	8	23,6	10	2,36
Prooduct 3	Carrot sticks	10	18	8	12,9	10	1,29
Prooduct 4	Cherry tomatoes	10	12	8	8,6	15	1,29
Prooduct 5					0,0		0,00
Prooduct 6					0,0		0,00
						Total percentage (must be 100):	Sum of respiration rates in the mix:
						100	14,21

All green fields are input fields
All blue fields are result fields

Note, the values in the illustration are just examples (not real data).

You can find the calculation tool in the members area on the website.

In this tool you can fill in your own data from your respiration measurements. The tool has an extra function where you can use your respiration data. If the individual components of the mixed salad are measured at different temperatures the tool will simply compensate for the temperature difference. Our advice is always to use data measured as close as possible at the same temperature. The temperature functions in the tool are based on theoretical calculations but practical measures at equal temperature will always be beneficial to use.

In general, we recommend that you should make you own small database with respiration data for your different relevant products.

It is also a good advice to test respiration rates of your products over a typical season as we know the respiration rates changes with seasons. Some products have a higher respiration rate in the beginning of the harvest season then in end of the season.

You should also be aware that different varieties very often have different respiration rates. Therefore, we recommend testing the different sorts/varieties of your relevant products, to gather the information on the variations, so you can continue to improve your product performance.

2.7 Save and load of data on the website.

A new function has been added to the website for all calculation and simulation pages. When you have updated the page with your input data, then you can press “save” for saving your data. Your data will be saved in the destination folder “downloads” (this folder name can vary, depending on settings and language of your PC / Mac). The website will generate a filename like Appizy + the date of today + a version number. With your explorer you can easily change the name of the file and move it to another folder on you PC / Mac.

When you want to load the file again, you must press “load” and you Explorer will open and you must choose the correct file for the upload.

The file is saved in a JSON format (JavaScript Object Notation) and can only be used for our website.

2.8 Simulation of data.

You can use the simulator tool on the website, to optimize the permeability (microholes/laserperforations) of your packaging material, and also to “simulate what happens if”. For example if the desired temperature changes or if the type of packaging changes from a “pillow bag” to a tray with a sealed lid. And also for many other factors that can change over time.

Screenshot of the simulator page in www.danfresh.dk the US version is identical except for dimensions and weight in inches and ounces, se more at www.extendedshelflife.com

Packaging data:

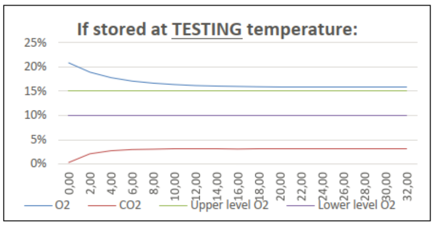
Bag inside width:	300	mm
Bag inside height:	200	mm
Overlap vertical:	13	mm
Sealing width (top and bottom) total:	13	mm
Bag = 1 Trayseal film = 2	1	bag
Bag content:	150	gram

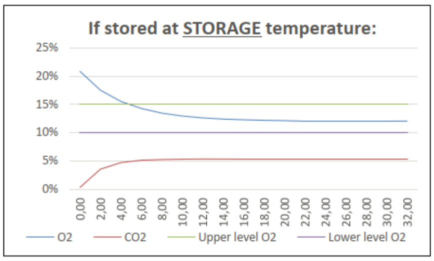
Respiration data:

Product name:	Product name	
Respiration rate:	20	ml O2 kg/hr
Measured at testing temperature:	5	C
Storage temperature:	10	C
Respiration rate at storage temp:	34,3	ml O2 kg/hr
Reccomended upper limit for O2:	15,0	%
Reccomended lower limit for O2:	10,0	%

Modeling data:

Measuring range:	2	hours
O2 level at start - default 20,9 %:	20,9	% O2
CO2 level at start - default 0,3 %:	0,3	% CO2





Permeability data:

1. layer thickness:	25	Micron
2. layer thickness:	0	Micron
1. layer material:	OPP	
2. layer material:	None	
Film permeability - TR O2:	2150	ml/m2/24h/atm
Film permeability - TR CO2:	8600	ml/m2/24h/atm
Hole size - diameter:	90	micron
Hole distance mm:	30	mm

Results

OTR given by the film per m2:	2150	ml/m2/24h/atm
OTR given by the holes per m2:	8134	ml/m2/24h/atm
OTR in total per m2:	10284	ml/m2/24h/atm
No. of holes per linear meter:	33	holes per meter
Number of holes per bag:	7	holes per bag
OTR given by the film per bag:	281	ml/m2/24h/atm
OTR given by the holes per bag:	1062	ml/m2/24h/atm
OTR in total per bag:	1343	ml/m2/24h/atm

I will here walk you through the different sections and give you hints and tips for the best use of our services from our websites.

Packaging data section:

The calculations on the website is based on the three most common packaging types for packing produce like salad and vegetables: HFFS (Horizontal Form Fill Seal) and VFFS (Vertical Form Fill Seal) and tray seal packaging, also called top seal.

Packaging data:

Bag inside width:	300	mm
Bag inside height:	200	mm
Overlap vertical:	13	mm
Sealing width (top and bottom) total:	13	mm
Bag = 1 Trayseal film = 2	1	bag
Bag content:	150	gram

The width and height is simply the inside dimensions of your packaging measured in mm, if you use the US version, you will see all the packaging dimensions in inches.

Overlap vertical is the width of the vertical seal on the backside of your bag

Sealing width top and bottom is the total width of you seal including the mm. of film outside the seal.

For all HFFS and VFFS bags the bag type is 1, if your packing is a trayseal/topseal type, then the type is 2. For other types of packaging, please contact us.

Bag content is the weight of your packed product in grams, if you are using the US version of the website, then the units are here in ounces.

Respiration data section

Respiration data:		
Product name:	Product name	
Respiration rate:	20	ml O2 kg/hr
Measured at testing temperature:	5	C
Storage temperature:	10	C
Respiration rate at storage temp:	34,3	ml O2 kg/hr
Reccomended upper limit for O2:	15,0	%
Reccomended lower limit for O2:	10,0	%

In this section, the focus is on the measured respiration of your product, please refer to the Handbook chapter: 2.3 Measuring respiration for more information.

In the field: Product name, you should write the name of your product. The respiration and temperature are from your measurements.

The storage temperature is a little difficult, we normally define this as the temperature your product is mostly exposed to over the longest time. In many cases this is the temperature in the shops, but it can also be the warehouse temperature. Please be aware that the shop temperature can differ over time, even if the product in the shops is kept in a upright standing open refrigerator, there can be quite big variations in the temperature in the top and bottom and in the front and back. Nowadays many shops have upright refrigerators with doors, these are better, but we recommend you make a test of temperatures in your typical supermarkets. You must input the temperature you find most relevant. In the US version of the website, the temperature is measured in Fahrenheit -F, for all other markets the temperature is measured in centigrade -C.

In principle you can fill in any relevant storage temperature. If the storage temperature differs from the temperature you used for measuring respiration, then the website will recalculate your respiration rate to meet your entered temperature.

Example:

You have measured the respiration of your product at 5 degrees C to be 20 ml O2 kg/hour. The calculations on the website have integrated elements, based on Q10 models developed by Hoff and Arrhenius. This gives you the possibility to calculate the expected respiration rate at other temperatures than the temperature where you have measured the respiration. From the example above you can see that the product has a corresponding respiration of 34,3 ml O2 kg/hr if the temperature increases to 10 degrees C. In principle you can use this calculation for any temperature that differs from the temperature used for you respiration measurements but, please note that uncertainty increases with an increased difference in the two temperatures. So our advice is that you should measure the respiration at a realistic temperature, that is as close to the storage temperature as possible. A bigger difference then 5 - 8 degrees C, between temperature used for measuring respiration rate and storage temperature is not recommended.

Recommended upper and lower level of O2, is simply just two horizontal lines on the graph that indicates the upper and lower level of recommended O2. There are no rules or guides to these lines, however this gives a good visual indication in the charts of where you can see the ideal level of O2 for your product.

The two indication lines does not have any influence on the calculations, you can put them where you want.

We recommend using the indication lines for your own understanding and reading the charts. In the literature you can find information on recommended or target levels of O2 in the packaging, There are many opinions about the optimum level of oxygen and we suggest that you use the "Fact sheets" from UC Davis as a guideline. You can find a link to these fact sheets in the "Home" section on our website.

One example from the UC Davis website:

Broccoli:

Rates of Respiration

Broccoli heads have relatively high respiration rates:

Temperature	0°C (32°F)	5°C (41°F)	10°C (50°F)	15°C (59°F)	20°C (68°F)
ml CO_2/kg·hr	10-11	16-18	38-43	80-90	140-160

The respiration rates of florets are slightly more than twice the rates of the intact heads.

Responses to Controlled Atmospheres (CA)

Broccoli can be benefitted by 1-2% O_2 with 5-10% CO_2 atmospheres at a temperature range of 0-5°C (32-41°F). Although under controlled conditions such low O_2 levels extend shelf-life, temperature fluctuations during commercial handling make this risky as broccoli can easily produce offensive sulfur-containing volatiles. As a result, a high rate of air exchange is recommended in standard marine container shipments of broccoli. Most modified atmosphere packaging for broccoli is designed to maintain O_2 at 3-10% and CO_2 at about 7-10% to avoid the development of these undesirable off-odor volatiles.

So, in this example the optimum level of O2 is at 1 – 2 % O2 and 5 – 10 % CO2. This is not possible in a packaging. With gas flushing you can flush you pack to start at these levels of O2 and CO2, but with the respiration of your product and the physics of your packaging material, this is not possible to achieve longer shelf life. O2 and CO2 will always try to balance out to levels of O2 and CO2 in the surrounding air. Therefore, you must consider a compromise between O2 and CO2, your packed product, and the packaging. The recommendation from UC Davis can also be seen as a compromise (the last 4 lines). It is often seen that if you keep a product at the recommended levels of O2 and CO2 for the longest possible shelf life, then you can end up with undesired off odors. So often it can be beneficial to target a level of O2 higher than the level recommended for the longest possible shelf life.

Please note that in most cases (when packing without gas flushing) the sum of the balance of O2 and CO2 will be close to 20,9 % O2. This means that if the level of O2 in the packaging (when the packaging material is OPP or laminates with OPP or PET is reduced to for example 10,0 % O2, then the CO2 will be close to 11 % CO2. If your packaging material is a PE based type then, and if level of O2 is reduced to about 10 %, then the balance with CO2 will be at a lower level (typical between 5 and 10 % CO2). This is because the CO2 permeability of PE is higher than other typical packaging materials used for packing produce. Please note that this fact can be beneficial in cases where you want to have a low level of O2 in your packaging and at the same time wants to have a relative low level of CO2, then PE based packaging materials can be a good idea for your product.

Modeling data section:

Modeling data:

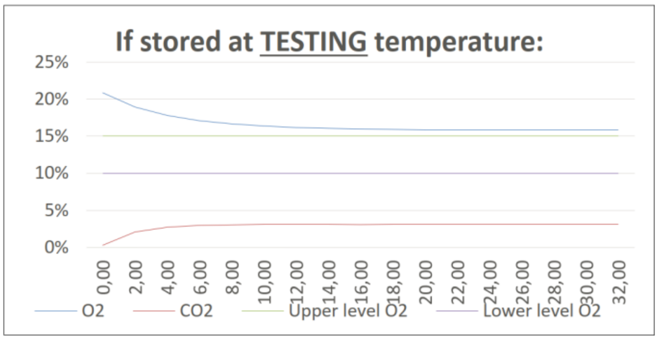
Measuring range:	2	hours
O2 level at start - default 20,9 %:	20,9	% O2
CO2 level at start - default 0,3 %:	0,3	% CO2

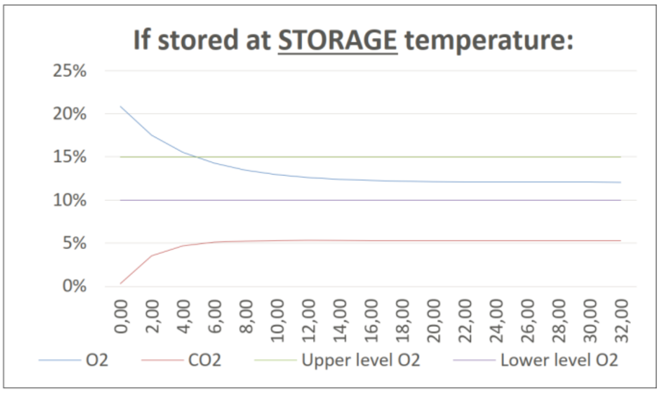
This section has basically two functions:

Measuring range on the graph controls the length of the charts, for example the value = 2 gives a time length in the charts of 32 hours (Showing the oxygen and CO2 values every 2 hours). If you have a slow or very quick respiring product, you can adjust this value up or down, the value in the chart will adjust accordingly. Important for you is to see the level of O2 and CO2 until it reaches its equilibrium (steady state or horizontal lines for O2 and CO2).

In case you are gas flushing your packaging, then you can adjust the time range to see oxygen and CO2 values calculation accordingly. For example, if you gas flush your packaging to 5 % O2 and 10 % CO2, then you can simply put these values in the fields.

Charts section:





Please note the important difference between the charts, the **upper** chart shows the result if your product is kept at the same temperature as you have measured the respiration.

The **lower** chart shows the result at the temperature you have typed here under storage temperature:

Measured at testing temperature:	5	C
Storage temperature:	10	C

Permeability data section.

Permeability data:		
1. layer thickness:	25	Micron
2. layer thickness:	0	Micron
1. layer material:	OPP	
2. layer material:	None	
Film permeability - TR O2:	2150	ml/m2/24h/atm
Film permeability - TR CO2:	8600	ml/m2/24h/atm
Hole size - diameter:	90	micron
Hole distance mm:	30	mm

In this section you can choose your packaging materials and the thickness of each layer. All calculations are for a two layer material. The website is programmed with some chosen packaging materials and you can enter the thickness of each of the two materials in the lamination:

OPP – CPP – PE – PET

And in the following thicknesses (micron): 12 – 20 – 25 – 30 - 35 – 40 – 45 – 50 – 55 – 60

These materials and thicknesses are typically used for the packing of produce, salad, fruits and berries. In case you need a material or thickness not mentioned here, then you please inform us and we will update the website with your material.

The film permeability is based on typical values for the different materials, some variations in these values are typical even for very standardized materials like OPP and PET

The **hole size** and **hole distance** are important values, in fact these values will tune your packaging to your product. Please note that we consider the hole to be circular round, some manufacturers make oval holes due to poor quality of laser system and if the holes are made at a too high process speed. We consider a good hole to have a hole ratio of less 1 : 1.2 (ovality)

By adjusting the hole size and hole distance you can adjust the permeability to exactly meet the requirements in level of O2 in the bag/packaging.

Results section:

The result section gives you all permeability information you need for specifying you needs, to you packaging supplier.

Results		
OTR given by the film per m2:	2150	ml/m2/24h/atm
OTR given by the holes per m2:	8134	ml/m2/24h/atm
OTR in total per m2:	10284	ml/m2/24h/atm
No. of holes per linear meter:	33	holes per meter
Number of holes per bag:	7	holes per bag
OTR given by the film per bag:	281	ml/m2/24h/atm
OTR given by the holes per bag:	1062	ml/m2/24h/atm
OTR in total per bag:	1343	ml/m2/24h/atm

Please note that most packaging manufactures, are not able to transform the OTR (Oxygen Transmission Rate) information to a value, they can use for adjusting their laser systems.

Therefore, we recommend you instead to specify, only the hole size and the hole distance, or eventually holes per linear meter / holes per package.

Please also note that the number of holes per linear meter or per 10” and holes per package are rounded values, in specifications with few number of holes this can be quite important. For example, if your bag is specified to 2 holes, this information is a rounded value that might be pounded up from 1.6 holes per bag or down from 2.4 holes per bag, therefore hole distance is a more precise information.

Another suggestion is to make the hole pattern according to a print/photo mark in the printed design many laser systems can make the laser holes after a specified distance after the print/photomark and with a specified distance between the holes. It’s difficult for us to give specific information about this function in different systems, so please speak to your packaging supplier about the possibilities in specifying the needed number of holes.

If there are any unanswered questions, then please don’t hesitate to contact us with your questions.

We wish this information will help in making you confident in not only conducting the respiration studies but in also specifying the laser microperf size and numbers to meet the target MAP so that you can achieve extended shelf life for your produce. Good luck with the testing and optimizing of the product and process.

Kim Berg Jensen

Denmark

Dr. Neeraj Sharma, Ph. D

US