Lecture 03

Equilibrium Moisture Content

Drying & Storage Engineering

(PFE-304)

Importance of EMC

- EMC gives us the idea whether the material will gain or loose moisture at a particular atmospheric condition.
- It also gives an idea about rate of moisture removal.
- EMC helps to determine drying characteristics.
- Prediction of moisture content level using heated air with the help of EMC

Methods for determination of EMC

(1) Static method
(2) Dynamic method

Static method

- In static methods, to bring the atmospheric air to desired relative humidity levels different concentrations of sulpheric and hydrochloric acids are used.

- Static methods are generally too much time consuming, and to **bring** the grain to equilibrium condition by acids, 3-4 weeks are required.

- Thus in case of higher humidity and high temperature conditions, chances of attack of molds are high.

Relative humidity values on the different concentration of Sulphuric acid solution in water

Temperature, °C	Acid by weight basis, %			
	20	**40**	**60**	**80**
10	87.4	56.6	15.8	3.8
20	87.4	56.7	163	4.7
30	87.4	56.6	17.0	5.7
40	87.4	57.5	17.8	6.9
50	88.8	58.0	18.8	8.2

Dynamic methods

(i) Desorption method : In this method, the property of dry air to absorb moisture from moist grains is employed.

- Moist grains are put in an airtight container.
- When the air comes in equilibrium to grain its relative humidity is measured by an electric hygrometer or by a hair hygrometer.
- Since the container has little quantity of air, it reaches in equilibrium with grain in short period.

(ii) *Isotenoscopic method*: This method also employs absorption of moisture by dry air to determine grain EMC

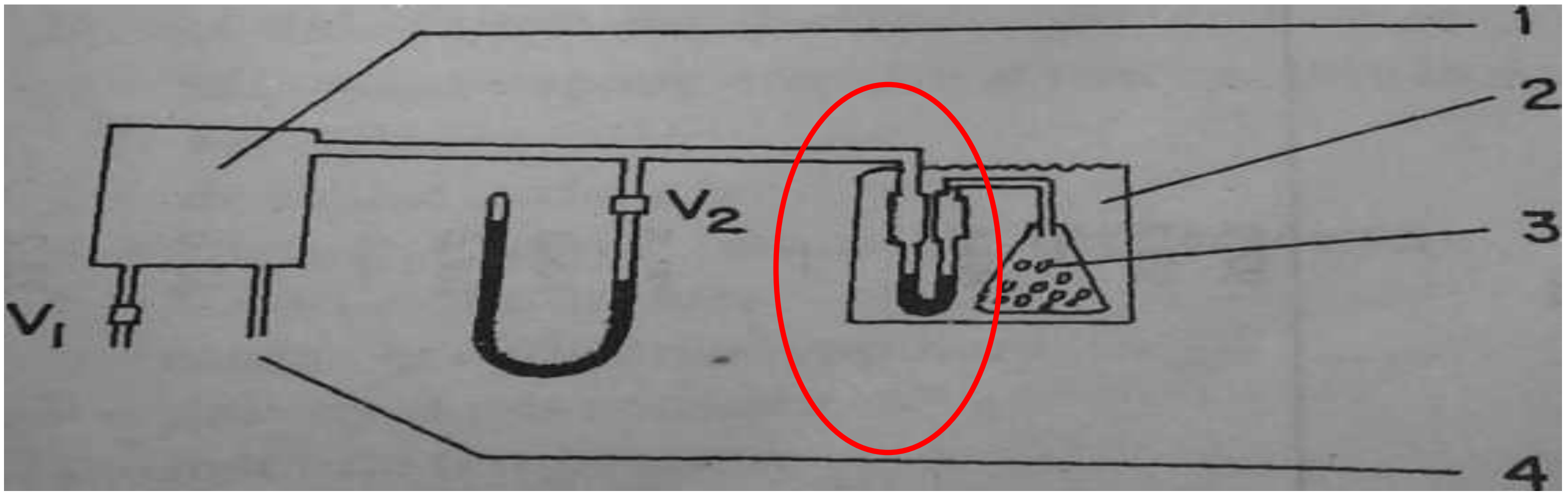


Fig. **3.4** : Schematic diagram of an isotenoscope
1. vacuum storage jar 2. constant temperature water bath **3.** sample flask **4.** to vacuum pump

- Isotenoscope is a U tube filled with the liquid of negligible vapour pressure.
- The arms of the tube has an enlarged section above the level of liquid to prevent drawing of the liquid out of the tube while evacuating or readmitting air to the flask

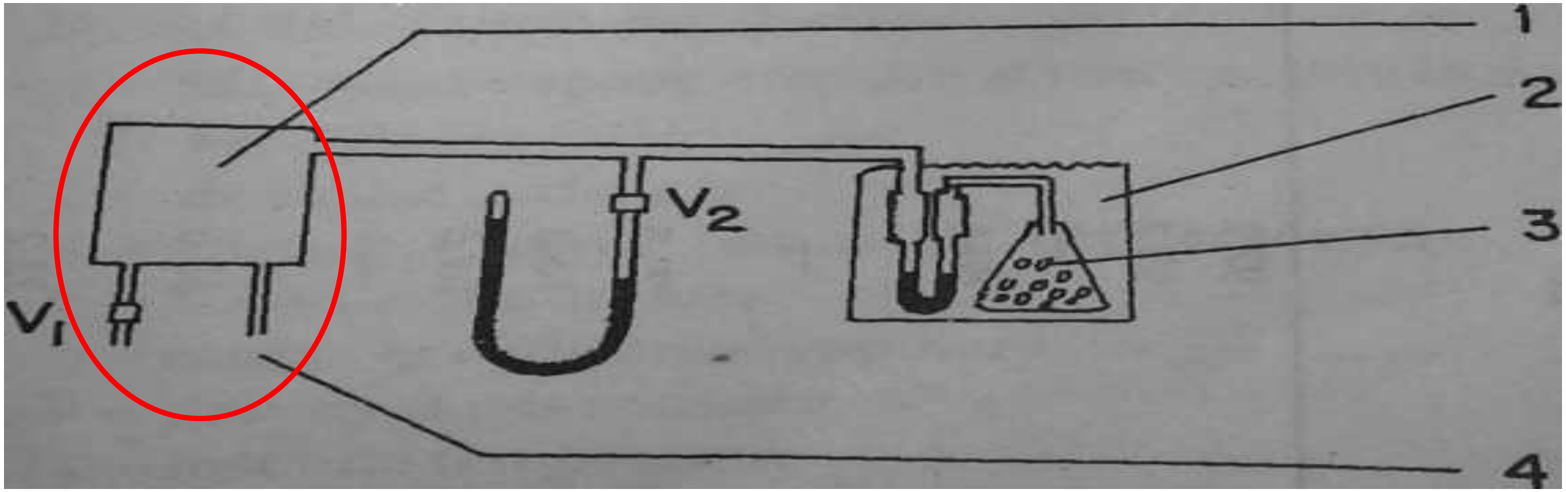
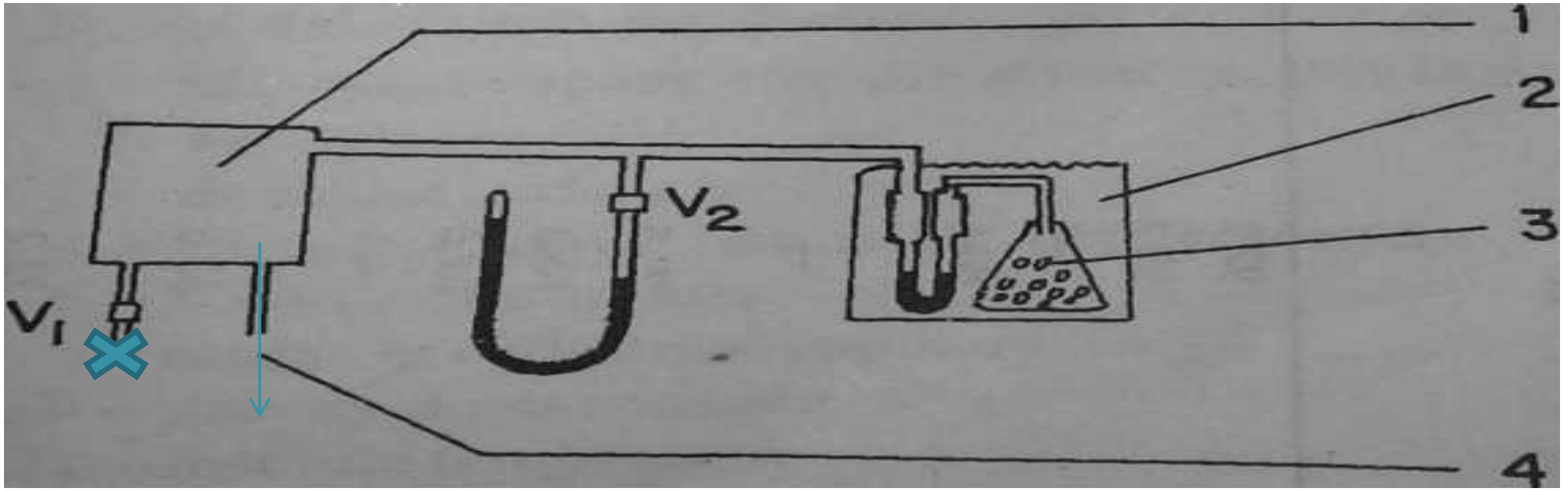
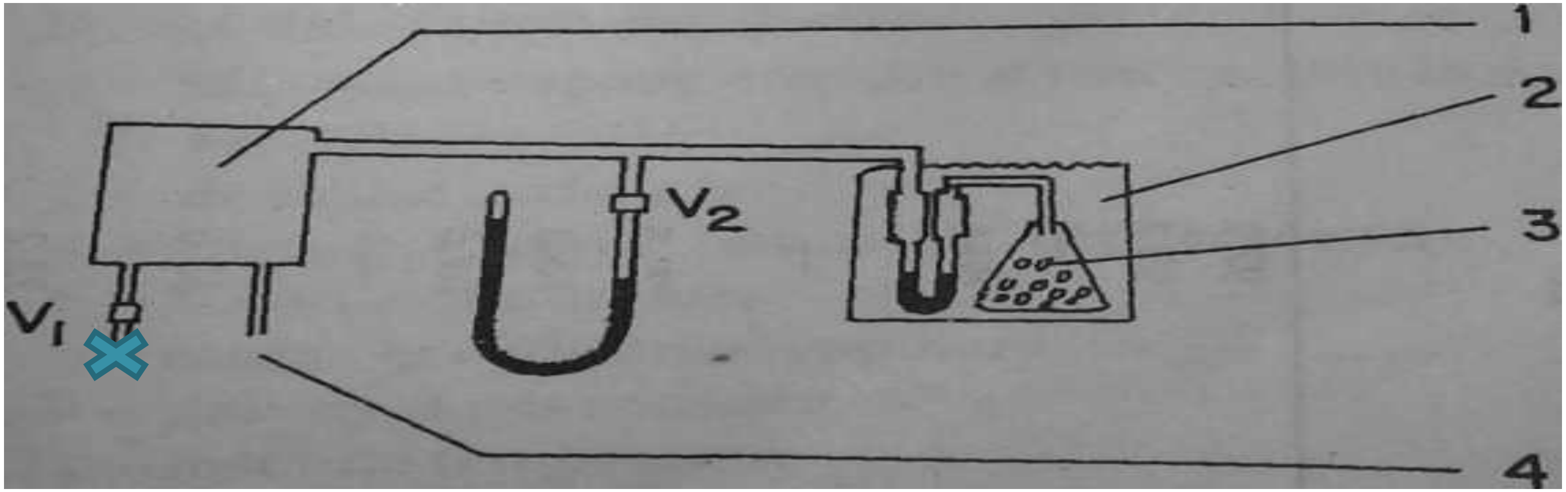


Fig. **3.4** : Schematic diagram of an isotenoscope
1. vacuum storage jar 2. constant temperature water bath
3. sample flask **4.** to vacuum pump

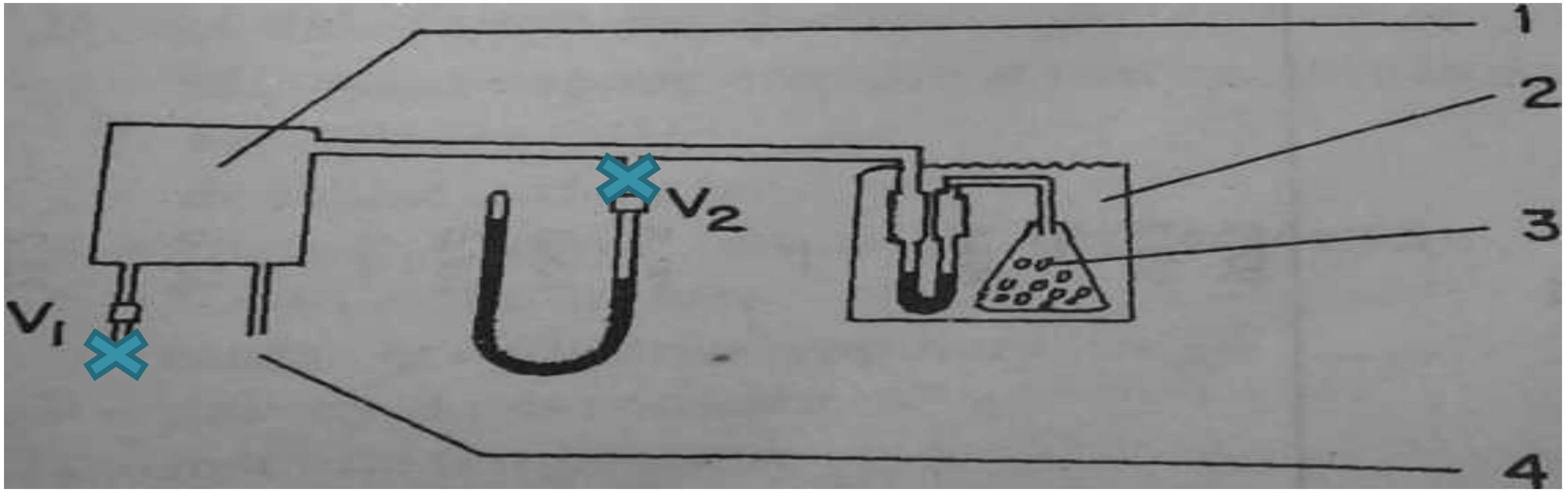
- The isotenoscope is connected to a vacuum pump through a vacuum storage jar.
- Atmospheric pressure can be brought back into this jar by means of a valve V_1.



- The V_2 is a shut off valve connecting closed end of mercury manometer to the vacuum system.
- In operation, valve 'V_1' is closed while all air is evacuated from the flask, the vacuum storage jar, and from the system



- Under this condition, vapour pressure builds up in the flask which forces the liquid in the two arms of the isotenoscope to dissimilar level.
- The level of the liquid is then equalised by bleeding a small amount of air into the vacuum storage jar.
- This equalization pressure is continued until vapour pressure built up in the flask has reached a maximum for the temperature of water bath.



- Valve 'V_2' is then closed and the absolute pressure indicated in the manometer is read.
- The isotenoscope is removed from the flask and the flask is closed by a properly weighed stopper.
- The weight of flask with sample is recorded to determine sample moisture content.

EMC MODELS

For determination of EMC of agricultural products many **theoretical, semi-theoretical,** and **experimental** models have been proposed.

But, none of the theoretical EMC equation is found to predict or to provide the EMC values correctly in the entire range of temperature and relative humidity values.

EMC models :

I. Kalvin equation :

- Kalvin in 1871 has giving the model of moisture adsorption by solid material.
- For evolving the model, the phenomenon **of capillary condensation in pores of solid materials** was considered.
- The relationship between the vapour of water present in capillary and saturated vapour pressure at same temperature is the basis of capillary condensation theory.
- The utility of above equation for grain EMC determination is limited in condi-tions of relative humidities above **95%** when the action of capillary condensation takes place.

The Kalvin equation is as under :

$$\ln \left\{\frac{P_v}{P_{vs}}\right\} = \frac{2\sigma V\, cos\alpha}{rRT_a}$$

Where,

P_v = Vapour pressure of grain

P_{vs} = Saturated vapour pressure at temperature in equilibrium with the system

T_a = Absolute temperature

σ = Moisture surface tension

V = Volume of moisture

r = Radius of cylindrical capillary

R = Universal gas constant

EMC models :

2 Harkins-jura equation:

- This model is based on the theory of existence of a potential field above surfaces of solid materials.
- In this concept, the work required to adsorb or adsorb a water molecule is the *sum* of work required to overcome vapour molecule to come on surface and the work
-

$$\ln\left\{\frac{P_v}{P_{vs}}\right\} = d - \frac{e}{V^2}$$

Where,

d & e = product constant depend on tem

The Harkins-Jura equation does not predict satisfactorily accurate EMC values when the relative humidity is more than **30%.**

EMC models :

3 Chung-pfost equation :

Chung-Pfost has proposed an equation for determina-tion of EMC on the basis of potential field theory.

The equation is given below :

$$\ln\left\{\frac{P_v}{P_{vs}}\right\} = -\frac{A}{RT}exp(-BM)$$

Where,

R = universal gas constant

T = absolute temperature, °***K***

A & B = constant dependent upon grain temperature

M = moisture content, % ***(db)***

The above equation provides fairly accurate EMC values of grains between **20 to 90%** relative humidity values.

EMC models :

4 Henderson equation :

Handerson in 1952 has proposed an equation for EMC determination. This EMC equation is very much popular and based on the Gibbs' adsorption equation.

The following equation for the EMC curves has been derived by Henderson.

$$1 - rh = e^{-CTMe^{n}}$$

Where

rh = relative humidity, decimal

T = absolute temperature, °*K*

M = *EMC*, %

C & n = constant, dependent on crop type and temperature Out of the above described

Theoretical, semi-theoretical or empirical equation, no single relationship can predict grain's ***EMC*** values in the full range of relative humidities and temperatures generally encountered.

Numerical problems based on Henderson's equations

Problem : Calculate the equilibrium moisture content of brinjal seed at relative humidity of 10% and temperature of 50°C using Henderson's equation. Given that constants *c* is 6.5×10^{-6} and *n* is 1.8.

Numerical problems based on Henderson's equations

Problem : Determine the values of constants *c* and *n* from the Henderson's equation for the following data obtained under two different conditions of EMC studies of sunflower seed.

Condition	Relative humidity, %	Temperature °C	EMC, % (db)
1	50	40	10
2	70	50	13

Numerical problems based on Henderson's equations

$$1 - 0.7 = e^{-[C \times (50+273) \times 13^n]}$$

or, $$0.3 = e^{-[C \times 323 \times 13^n]}$$

or, $$e^{-1.204} = e^{-[C \times 323 \times 13^n]}$$

or, $$1.204 = c \times 323 \times 13^n$$

Dividing equation (ii) by equation (i), we get

$$\frac{1.204}{0.693} = \frac{C \times 323 \times 13^n}{C \times 313 \times 10^n}$$

or, $$\left(\frac{13}{10}\right)^n = 1.68$$

$\therefore$ $$n = 1.98$$

Substituting the value of n in equation (i)

$$0.693 = c \times 313 \times 101.98$$

or, $$c = 2.32 \times 10^{-5}$$

Numerical problems based on Henderson's equations

Q. 1. Determine the equilibrium moisture content of wheat at 27°C and 80% relative humidity using Henderson equation. Assume $C = 10.06 \times 10^{-7}$, and $n = 3.03$ for wheat.

EMC=16.98% db

Q.2. Using the Henderson's equation, calculate the equilibrium moisture content of Soybeans at 25°C and 80% relative humidity. Take, $C = 6.5 \times 10^{-6}$, and $n = 2.8$ for Soybeans.

EMC=11% db

Q.3. Determine the values of C and n in Henderson's equation for following data obtained under two different conditions.

$C = 1.2 \times 10^{-5}$, $n = 2.1674$

Condition	Relative humidity, %	Temperature, °C	EMC, % db
1	30	50	8
2	70	50	14

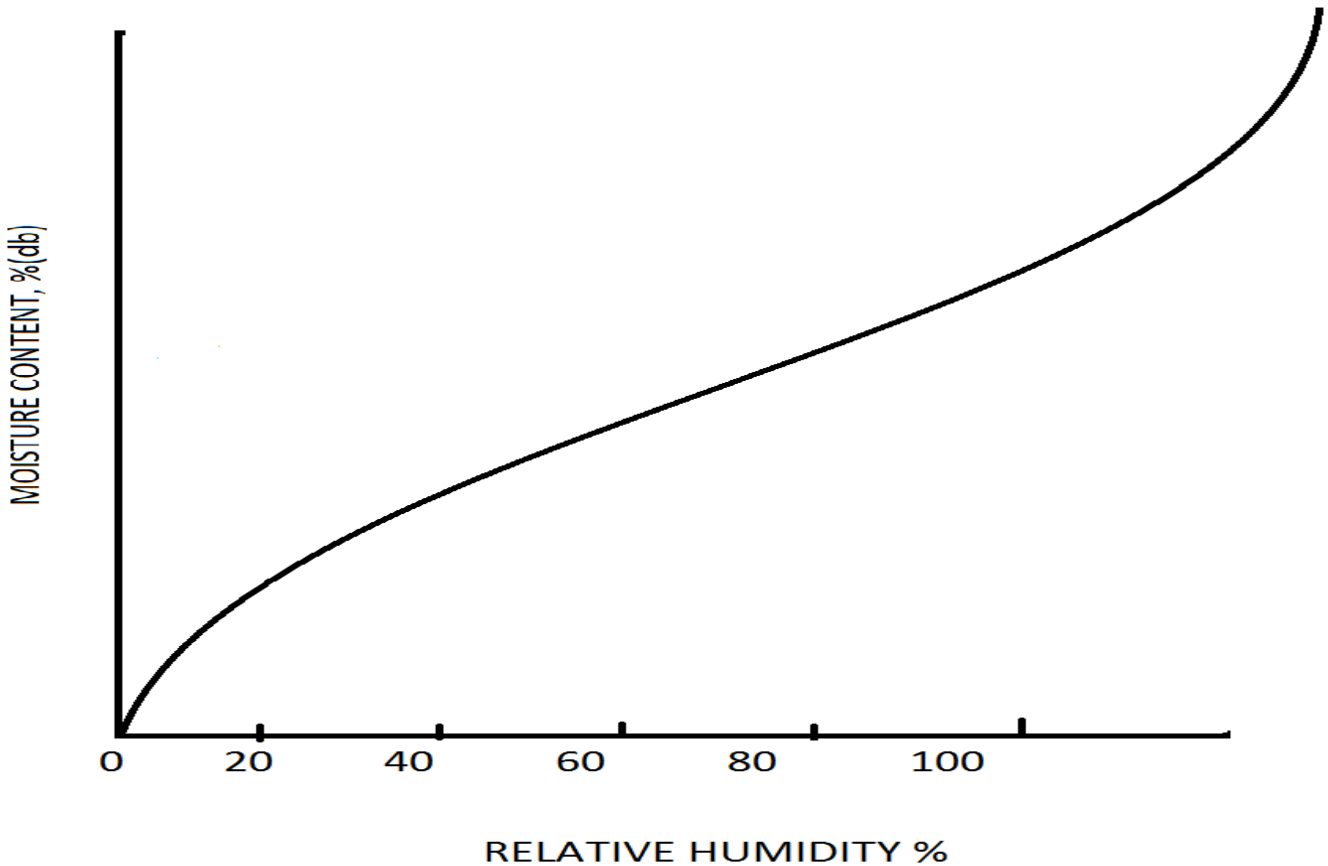


Fig. Equilibrium moisture curve

Hysteresis effect :

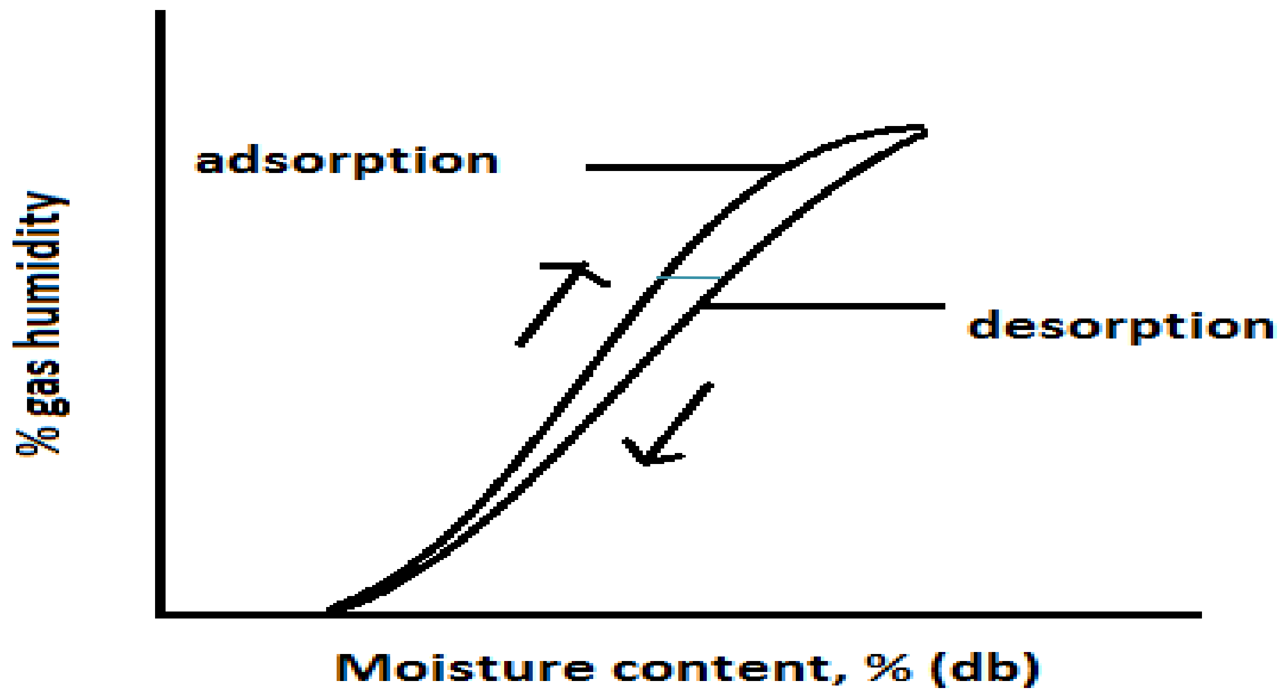


Fig. Hysteresis effect