Chapter One

Introduction

1.1 Preface

Expandable polystyrene is the plastic material with a chemical composition of C_8H_8 used for the molding of expanded polystyrene products. It is manufactured in the form of very small polystyrene beads with average molecular weight between 160,000 and 260,000 and contains blowing agent, usually pentanes or butane. The bead diameter can vary between 0.2 mm to 3.0 mm. [1]

EPS has special properties due to its structure. Composed of individual cells of low density polystyrene, EPS is extraordinarily light and can support many times its own weight in water. Because its cells are not interconnected, heat cannot travel through EPS easily, so it is a great insulator. EPS is used in flotation and marine's devices, insulation, packaging, and picnic coolers.

1.2**Properties of expanded polystyrene (EPS): [2]**

Expanded polystyrene has certain desirable properties because of its structure. It is good insulator against heat and sound. It can be used as a building material or a design element, and can be molded into many shapes for a number of house hold uses as well.

i. Shock Absorption:

EPS exhibits excellent shock absorbing characteristics making it the first choice for construction, electronic products, computers and chemicals. Its predictable characteristics enable packaging to be accurately designed to suit each product, and provide cost effective.

ii. . Durability:

EPS is an inert, organic material, and therefore will not rot and is highly resistant to mildew. It provides no nutritive value to plants, animals, micro organisms or rodents.

iii. Moisture Resistance:

EPS is a closed cell material and does not readily absorb water, unless subjected to prolonged saturation. Even in this situation it maintains its shape, size, structure, physical appearance and approximately 85% of its insulation value. The ability of EPS to resist moisture is exemplified by its widespread use in fishing floats and marinas, involving exposure to water for prolonged periods of time.

iv. Light Weight:

EPS is an extremely light weight material. Typically weighing between 12 and 30 kg per cubic meter, EPS has many advantages over other materials equally in building situations; this lightweight characteristic is a major advantage in providing structural design economies. Additionally, when shaped to provide intricate architectural features, it allows architects the freedom to create historical, innovative and economic enhancements to buildings while still meeting strength and earthquake codes.

v. Safety:

EPS is environmentally friendly, safe and requires much less energy to produce than many other materials In applications where fire resistance is necessary or desirable, such as building products, EPS is supplied containing a flame retardant which in normal use prevents ignition of the EPS if exposed to a flame. In a fire situation EPS generates less heat and smoke than most timbers and wood based products.

vi. Ease of Use**:**

EPS is supplied either moulded to the exact shape required for its use, or can be easily cut and shaped when required to suit any application. Its light weight makes handling easy and safe. EPS does not irritate the skin and is non allergenic.

vii. Fire Characteristic:

Like all organic materials, expanded polystyrene is combustible flammable. Its burning behavior depends largely on the polystyrene grade in question. A distinction has to be made between products without fireproofing additives and products containing additives. Expanded polystyrene that contains flame retardant makes it more difficult to ignite and slows the spread of flame noticeable.

viii. Chemical Properties:

EPS is resistant to almost all aqueous media including dilute acids and alkalis, methanol, ethanol and silicone oils. It has limited resistance to paraffin oil, vegetable oils, diesel fuel and Vaseline. Is also resistant to mineral waxes of the kind used to guard against corrosion, provided they contain no solvent resistant to water and all aqueous solutions of salts.

ix. Ability to be recycles:

In order to expand polystyrene steam is applied to tiny grains of styrene that contain a minute amount of pentane. The expanded beads are then moulded into a shape or a large block which is then sliced into boards. The minuscule amount of pentane gas used in the process has no known effect on the upper ozone layer. Any waste EPS produced during manufacture is reground and recycled back into the manufacturing process. Any additional waste EPS from other sources can be easily recycled or used in a wide variety of other products, coat hangers, imitation wood for benches etc. EPS is an excellent example of an efficient use of a natural resource; the transformation process uses very little energy. Manufacture and use of EPS does not generate any risk to health or the environment. [3]

1.3 Applications:

i. Construction

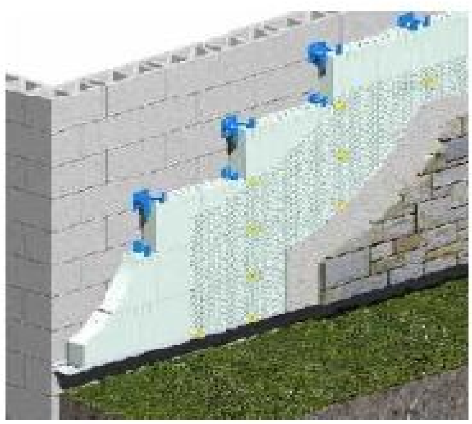

Figure 1-1 thermal insulation

Source: Harbor Foam's manufacturing.

http://www.harborfoam.com

The main application of EPS in construction and building industry is:

- Floor and thermal insulation.
- Structural insulated panels.

- Insulated concrete forms.
- Roofing insulation system.

ii. Packaging

Figure 1-2 applications of EPS in packaging

Source: Harbor Foam's manufacturing.

http://www.harborfoam.com

EPS being expanded to very low densities is one of the most lightweight packaging materials available, the main application of EPS in the Packaging is:

- Picnic coolers.
- General purpose packaging.
- Original equipment manufacturer packaging
- Air condition insulation.
- Computer cushioning.
- Thermal protective packaging.
- Pharmaceutical (shipping containers).
- Fabricated packaging:
- End caps.
- Edge protectors.
- Produce packaging:
- Flotation
- Water tank floats.
- Marine's flotation.
- Toys.
- Specialty foams:
- Cups and containers.
- Coffee cups.
- Take –out containers.

iii. Agriculture:

Figure 1-3 seed-trays.

Source: Harbor Foam's manufacturing.
http://www.harborfoam.com

EPS Sintered expanded polystyrene finds extensive application in agriculture for the manufacture of seed-trays and for frost protection of fruit tree grafts.

iv. Sporting Goods

Figure 1-4 Sporting Goods

Source: Harbor Foam's manufacturing.
http://www.harborfoam.com

Light weight and excellent impact resistance make EPS the material of choice for the fabrication of protective helmets for various sports and leisure activities (Motor sports, cycling, skiing).

1.4 Objectives:

The objective of this research is summarized in the following points:

- Study the pre-expansion process.
- Determine the effect of the expansion pressure, expansion time and beads size on EPS bulk density.

1.5 Literature Review:

In their study titled "The Analysis of the Influence of the Polystyrene Patterns Shaping Parameters on the Resistance Properties" T. Pacyniaka, K. Buczkowskaa, W. Bogusb, they [4] presented the technology of making foam plastics patterns used in casting as well as the final shaping stand. The analysis of the sintering process was carried out aiming at determining the influence of the pressure and the time of sintering on the flexural strength properties. The analysis of the research results confirmed that when the sintering pressure grows to the value of Pa=1,7 bar the flexural strength also increases, when the pressure value is higher than that, the degradation of the material takes place and the strength properties decrease. In order to obtain casts of high precision and smoothness of the surface it is necessary to pay attention to the following:

Good quality of the surface. Low price and high strength of the patterns.

The following materials are used to produce patterns: expanded Polystyrene EPS known as polystyrene, poly methyl methacrylate (PMMA), polyethylene (PE), polypropylene (PP) and polycarbonate (PC).

The materials for lost foam patterns used in the process of full Fore cast making should guarantee:

- relevant density of the pattern.
- good quality of the pattern surface.
- dimension stability of the pattern.
- relatively fast gasification.
- Being environmentally friendly.
- After gasification they should not leave any hard parts.
- Low price.

The Lost Foam technology consists of two basic stages of the pattern making with the above mentioned parameters. The first stage is the so called process of preliminary foaming in which the granules of the extended polystyrene are subjected to initial thermal treatment, drying and activation. Then, the granules are shot with the help of a pneumatic pistol to metal matrixes which reflect the shape of the patters, later they are subjected to another thermal treatment – the so called sintering or re-foaming. The ready pattern is taken from the matrix after being cooled first. Aiming at the lowest possible bulk density of the foamed granules it should be remembered that when the density decreases the strength and hardness of the polystyrene also decrease, thus the surface quality deteriorates. During the final shaping process the most important parameters are the time and the temperature. In practice, it is easier to control the steam pressure than the temperature. The density of the patterns should be controlled because it influences the following properties:

- Mechanical stability.
- Surface smoothness.
- Quantity of the produced gas.
- Shrinkage and pattern dimensions.

In their study titled" Dependence of Thermal Properties of Expandable Polystyrene Particle Foam on Cell Size and Density" Dow Olefinverbund GmbH, R&D EPS, Site Schkopau, was studied. [5] An approach to improve the efficiency of the thermal insulation behavior of expandable polystyrene (EPS) particle foams by diminishing the thermal conductivity is the reduction of the radiation term of the thermal conductivity by an adjusted enlargement of the cell size of the particle foam. This correlation was investigated in detail by the determination of the dependences of cell size and thermal conductivity on the densities of the particle foam over a wider range using samples of expandable polystyrene particle foams showing conventional fine cell size as well as enlarged cell sizes. Based on the dependence of cell size on foam density of fine cell EPS foams, an equation is given also covering foams of larger cells. At the same mean diameter of the foam cells, the thermal conductivity of the EPS foam is increasing with a decrease in foam density in the whole range of diameters investigated from about 50—350 μm. At the same foam density, the thermal conductivity is in general independent of the mean cell diameter of the EPS foam at high foam densities, whereas at lower foam densities, the thermal conductivity is decreasing with increasing mean cell diameter of the foam, in a range of foam densities from about 10—35 g/L. Subsequently, a practical model to describe the dependence of thermal conductivity of expandable polystyrene particle foam on cell size and foam density is proposed and discussed.

In their study titled "Expandable Polystyrene and Methods of Forming the Same" Joe Shuler, Jon Tippet, John Gaustad, Jose Sosat. [6]they describe Expanded polystyrene foamed articles and methods of making the same. The expanded polystyrene generally includes polystyrene selected from expandable polystyrene and extrusion polystyrene, the polystyrene exhibiting a molecular weight of from about 130,000 Daltons to about 220,000 Daltons; a melt flow index of from about 20 to about 30 and a density of from about 0.1 lb/ft^3 to about 10 lb/ft^3; and wherein the expanded polystyrene exhibits a density of from about 0.1 lb/ft^3 to about 10 lb/ft^3.

The foamed polystyrene articles are generally formed from expandable polystyrene or extrusion polystyrene, referred to collectively herein as EPS. The EPS may be formed by a variety of known processes. The equipment, process conditions, reactants, additives and other materials used in such polymerization processes will vary in a given process, depending on the desired composition and properties of the polymer being formed.

1.6 Boundaries:

Temporal boundaries: Republic of Sudan –Khartoum-Sudan University of Sciences & Technology-college of Engineering-Plastic engineering department-Almubarak Polystyrene Factory (MPF).

1.7 Thesis out line:

This thesis is divided into five chapters:

- Chapter one gives relevant information on Properties and application of expanded polystyrene and presents a literature review in EPS.
- Chapter two provides a background to Manufacturing process of Expandable polystyrene.
- Chapter three Review the materials were used and explains the experimental procedures to determine density of EPS.
- Chapter four present all the result in graphs form.
- Chapter five the conclusion and recommendations based on this study are summarized in this chapter.

Chapter Two

Background of Manufacturing process of EPS

2.1. Introduction:

EPS is the standard abbreviation for Expanded Poly Styrene; styrene is produced in industrial quantities from ethyl benzene.

EPS is obtained by polymerizing styrene and introducing small amounts of blowing agent as pentane is shown in figure 2-1. Both pentane and styrene are pure hydrocarbons. That means EPS consist only of carbon and hydrogen.

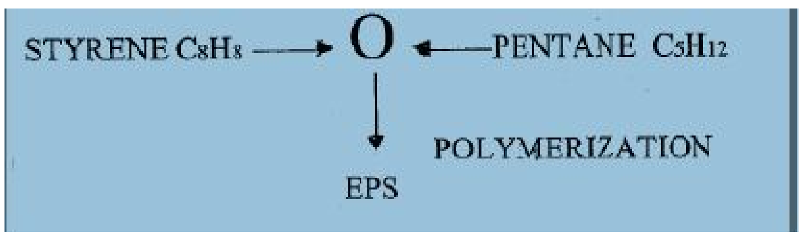

Figure 2-1 chemical composition of EPS

2.2 Manufacturing of Expandable polystyrene:

2.2.1 Polymerization and Impregnation:

Polymerization of styrene monomer used to be followed by impregnation of the polymerized polystyrene beads with a blowing agent. Today almost all process carries out in a one step process as shown in figure 2-2 the reaction occurs in a single reactor designed to control the temperature and pressure of the reaction. Styrene monomer and water is charged to the reaction kettle equipped with an agitator. Various chemicals are added to affect suspension of the monomer in water and to control the polymerized bead growth, molecular weight and other parameters necessary to produce the desired product. In the second phase of the process, the blowing agent is added under pressure and impregnates the soft polystyrene beads. The total batch cycle takes a little less than ten hours. When completed the entire batch is dumped to de-water the system. The beads are then dried. The beads are screened to obtain different bead sizes. They will be in different grades each has its own specification and use. Some are good for leak resistant containers, some are for impact absorption packaging applications, some are for general block and shape molding operations, etc. They are packaged is shown in Figure 2-3 and transferred to the EPS block manufacturer. [7]

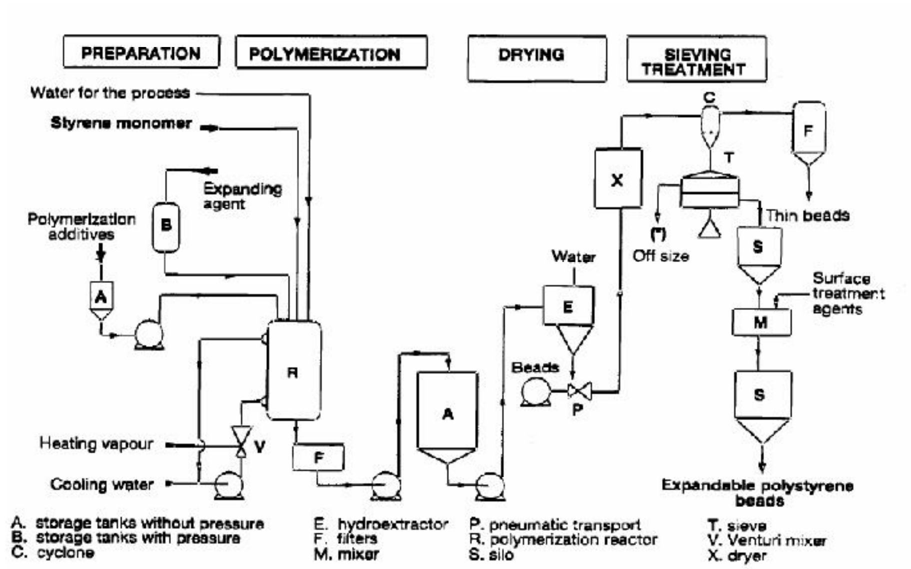

Figure 2-2 production process of EPS.

Source: Huntsman International LLC

http://www.huntsman.com/corporate/a/Innovation

Figure 2-3 packaged of EPS.

Source: www.BASF.com

2.2.2 Expanded polystyrene processing:

- Principle

The processing of expandable polystyrene into a molded part has three stages. In the first stage, the beads are fed to a vertical tank containing an agitator and a controlled steam input. This is referred to as pre-expansion. It is at this stage that the final material density is determined. The expanded beads, whose volume can be up to 40 times the volume of the raw beads prior to expansion, are then stored for several hours in the open air; in this stage, the vacuum developed in the cell structure of the pre-puff is allowed to come to equilibrium with the ambient atmosphere. After pressure stabilization, the pre –puff is fed to a closed mold and again subjected to steam heat. The pre-puff at this point has no room for further expansion and consequently fuses solid, producing a part defined by the mold. The production process is shown in Figure 2-4.

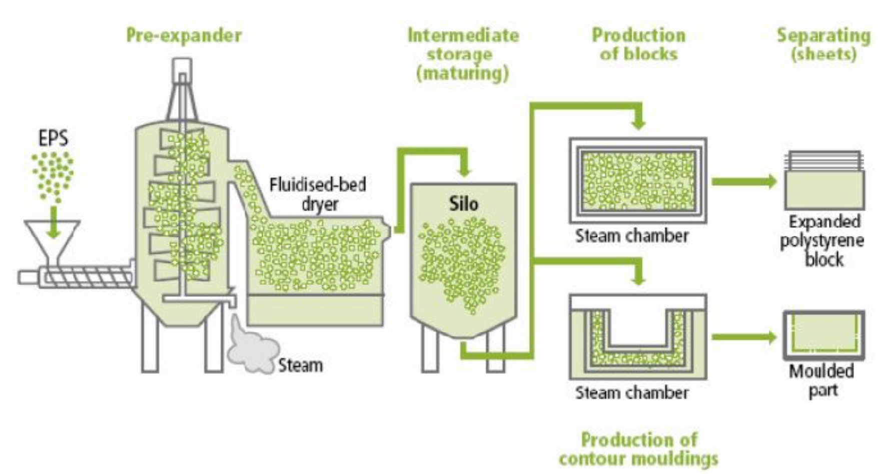

Figure 2-4 Manufacturing unit of moulded expanded polystyrene

Source : Europen manufacturers of expanded polystyrene . http://www.eumeps.org

- Pre-expansion

In order to mold the desired part at the required density, it is necessary to first generate a pre-puff particle the size of the required density. Expandable polystyrene, as received, has a density of about $640Kg/m^3$ .The pre-expansion of this raw material is carried out in vessels (pre-expanders) equipped with a controlled steam inlet, an air inlet, agitation and an automatic system for feeding the raw bead into the vessel.

By controlling the bead feed rate, the steam and air flow, and the agitator, the bead will soften at around 90℃,which is above the normal boiling temperature of the blowing agent, in this case pentane, at around 35℃. The internal vapor pressure will increase and these two simultaneous phenomena cause the bead to expand to the required density. The minimum density obtainable varies according to the product. It depends on factors such as the initial size of the beads and the blowing agent content.

This initial pre-expansion process can be carried out in either a continuous or batch (discontinuous) operation.

i. Batch pre-expanders:

The vessel is charged with an appropriate mass of EPS beads and purged with steam to remove most of the air. While the beads are agitated by a stirrer, further steam is admitted until the pressure reaches the desired value. Since the level of the material in the vessel rises as the beads expand, the beads can be discharged shortly after the required degree of expansion has been attained. The density of the pre-expanded beads can be adjusted automatically in different ways. The pressure in a batch pre-expander is shown in figure 2-5 can exceed atmospheric pressure, so that steam temperatures can be appreciably greater than 100°C.

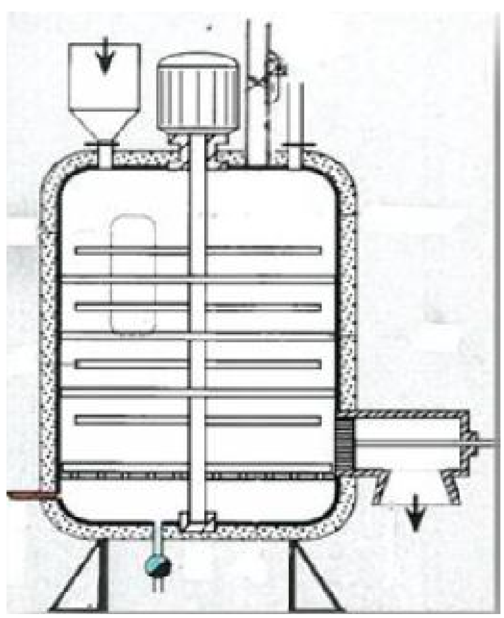

Figure 2-5- Batch pre- expanders.

Source: Huntsman International LLC

http://www.huntsman.com/corporate/a/Innovation

ii. Continuous pre-expanders:

A common type of continuous pre-expander is shown in figure 2-6 EPS is introduced continuously at the bottom and expanded beads leave at the top. As in a batch pre-expander, the beads are agitated by a stirrer. Steam is supplied steadily at a fixed rate; the inlet excess pressure is kept as low as possible. As a rule, the expanded beads leave the vessel through an opening at a constant height. The density can be adjusted automatically by varying the feed rate.

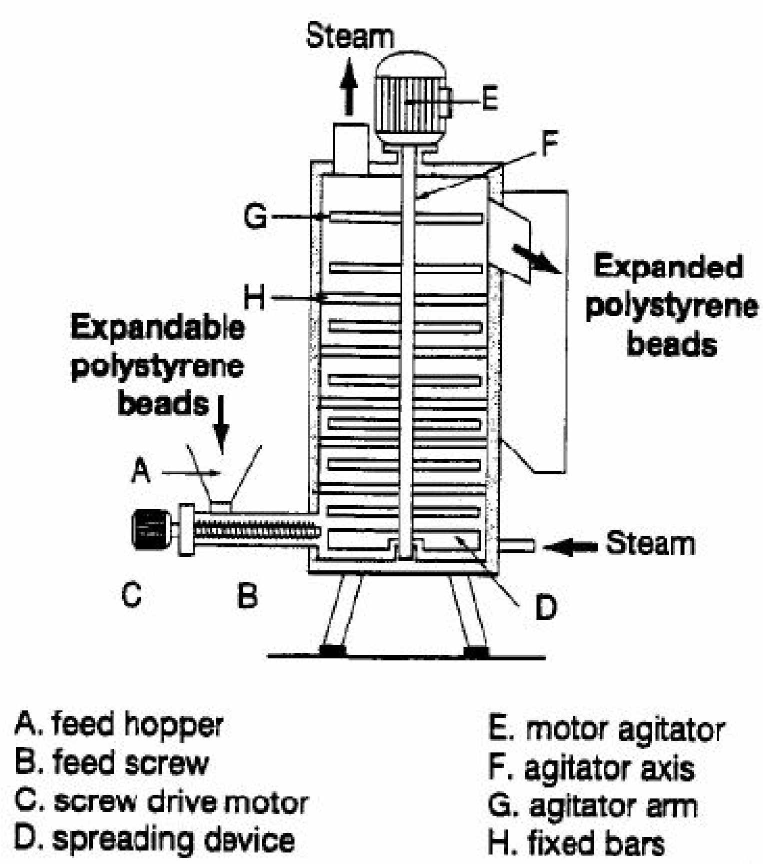

Figure 2-6 continuous pre-expanders.

Source: Huntsman International LLC.

http://www.huntsman.com/corporate/a/Innovation.

- Stabilization of the Pre-puff:

The pre-puff leaving the pre-expander and the fluid bed drier is transferred to plastic mesh holding bins and allowed to reach ambient temperature is shown in figure 2-7. This stabilization process is required to allow for air diffusion inside the beads in order to reach a pressure balance with the outside. The stabilization or maturing stage, also allows for the elimination of excess water contained in and on the surface of the pre-puff that is harmful to the molding process. For high density applications, the maturing stage also allows for the excess blowing agent to dissipate preventing most heat sensitivity in the mold.

Figure 2-7 plastic mesh.

Source: Hangzhou Fangyuan plastic machinery Co Ltd.

- Block molding:

Block molds is shown in Figure 2-8 are generally of the following dimensions: (1.0 to 1.25) m high, (0.5 to 1) m wide, and (6 to 8) m long. They are built in stainless metal (steel or an aluminum alloy). The six walls in contact with the expanded beads to be molded are usually stainless steel and have many openings (small holes, nozzles or slits less than1mm wide) that allow steam to enter, air to escape, and the vapor to penetrate inside the mold.

Behind each wall, there is a chamber called the vapor chamber which has a vapor inlet and a condensation water outlet (the lower part). Most block molds are equipped with a vacuum installation (tank or pump). The vacuum is employed to assist with the steam penetration and evacuation during molding.

Figure 2-8EPS block mould and vacuum installation.

Source: Hangzhou Fangyuan plastic machinery Co Ltd.

molding cycle generally lasts from 3 to 15 minutes depending on the type of block mold, the density of the pre-expanded beads and the type of raw material used. The temperature of the block when the ejected from the mold is about (90-95)℃ and the cells still contain a partial vacuum. For this reason, care must be exercised to insure that a temperature “shock “does not occur which could result in block shrinkage. Fresh molded blocks are usually allowed to stabilize for at least 24 hours.

- Cutting of the expanded polystyrene blocks:

EPS molded blocks are light weight but compact. These properties make it more difficult to cut. These blocks are cut by a cutting line consisting of computerized machine combining the series of thermal hot wire cutting tools to accomplish a smooth surface cut while still maintaining strict quality control dimensional tolerances. These tools heat the wires electrically and their resistance characteristics cause them to reach heat levels from 400 °F to 800°F. The wires are movement through the block to achieve the length and width cuts and then the blocks are pushed through the hot wires via a conveyer to achieve the desired thickness. Is shown in figure 2-9.

Figure 2- 9 Cutting machines of EPS.

Source: CLIMA - BEIJING TIME PROGRESSTECHNOLOGY DEVELOPMENT CO, LTD.

Chapter Three

MATERIALS AND METHOD

3.1. Introduction:

EPS density can be considered the main index in most of its properties. Most mechanical properties like Compression strength, shear strength, tension strength, flexural strength, stiffness, creep behavior depend on the density. The cost of manufacturing an EPS block is considered linearly proportional to its density. Non -mechanical properties like insulation coefficients are also density dependent.

3.2. Materials:

The raw material used and conditions:

For the test purpose BASF's expandable polystyrene – STYROPOR F 495 containing up to 3.8% pentane was used. Bulk density of expandable polystyrene is in range (20-40) Kg/m^3.The diameter of the beads in the range (0.3- 0.7 mm).

The samples have a volume of 1.0 liter of EPS. The study was carried out on batch pre-expander heated to the temperature of 85^oC. The conditions of the cycle are:

- Charge of raw material time 60 s.
- Time and pressure are variables.
- Dump material time 60 s.
- Drying time 7 hr.

3.3. Method:

Samples of EPS are taken from the plastic meshes where they are left for some time to stabilization before processing.

The density of the sample of EPS is determined as followed:

- A know volume of the material 1 liter is taken using a graduated jug is shown in figure 1-3.

Figure 1-3 graduated jug.

- This jug is weighted using an electronic scale is shown in figure3-2.

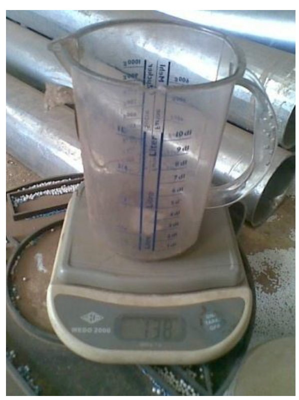

Figure 3-2 weight of the graduated jug.

Since the beads have spherical shape the actual density is higher than these value due to packing factor for spherical shape the packing factor is calculated as follows:

Packing factor (f) $= \frac{\text{volum of sphere}}{\text{volum of cube}}$ .... (3.1)

Volume of sphere $= \frac{4}{3}\pi r^3$ .... (i)

Volume of cube $= L^3$ .... (ii)

Substitute (i), (ii) in equation (3.1):

$$f = \frac{\frac{4}{3}\pi r^3}{a^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

As sphere and cube are touching each other there for:

$$L = 2r$$

$$L^3 = (2r)^3$$

$$L^3 = 8r^3$$

$$f = \frac{\frac{4}{3}\pi r^3}{8r^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

$$f = \frac{\pi}{6} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

The volume of the jug (1 liter) is multiplied by the packing factor in order to determine the actual volume of EPS.

- The jug fill of EPS to volume of 1 liter is shown in figure 3-3

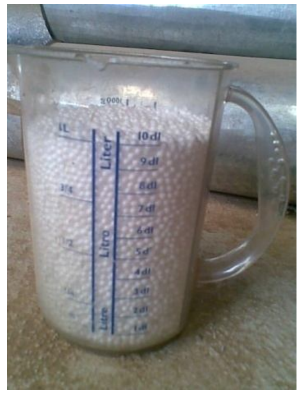

Figure 3-3 volume of EPS.

- And weighted using electronic scale balance see figure 3-4

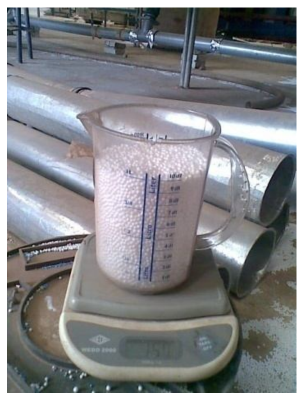

Figure 3-4 weight of EPS.

$EPS_{net\ wt} = EPS_{growth\ wt} - Jug_{wt}$ ………………………………… (3.4)

$$\text{Density} = \frac{\text{weight}}{\text{volume}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.5)}$$

Chapter Four

RESULTS AND DISCESSION

4.1. Introduction:

In this chapter we present experimental data in three charts, in this research used Excel program to draw the data in the form of curves.

4.2. The initial process of pre- expansion of EPS:

EPS is containing blowing agent (pentane) which the evaporating temperature is (28-30)℃ . In the process of expanding polystyrene in evaporation temperature of blowing agent a pressure inside the beads increases. The result of process of expanding polystyrene is stretching of the wall beads leading to an increase of its volume; from the softening temperature of EPS around 80℃ at the appropriate temperature of pre-expansion EPS (100-105)℃, followed a growth of beads volume up to several tens of times is shown in figure 4-1.

Figure 4-1 Beads of polystyrene before and after pre-expansion process
Source: www.Eps-system.com

4.3. Analysis of factors determining the pre-expansion process:

4.3.1. Effect of beads size on bulk density of EPS:

At the pre-expansion process . When size of beads increase the bulk density of EPS decreases is shown in figure 4-2.

Table 4-1 Dependence of bulk density from the time of expansion and the initial diameter of EPS beads.

Diameter of beads=1.0		Diameter of beads=0.63		Diameter of beads=0.4	
Expansion time (min)	Bulk density (Kg/m^3)	Expansion time (min)	Bulk density (Kg/m^3)	Expansion time (min)	Bulk density (Kg/m^3)
0.0	60.7	0.0	48.3	0.0	40.8
2.5	59.0	2.5	47.0	2.5	40.0
5.0	35.0	5.0	29.0	5.0	26.0
7.5	24.0	7.5	22.0	7.5	20.0
10	20.0	10	18.0	10	18.0
12.5	17.0	12.5	16.0	12.5	16.0

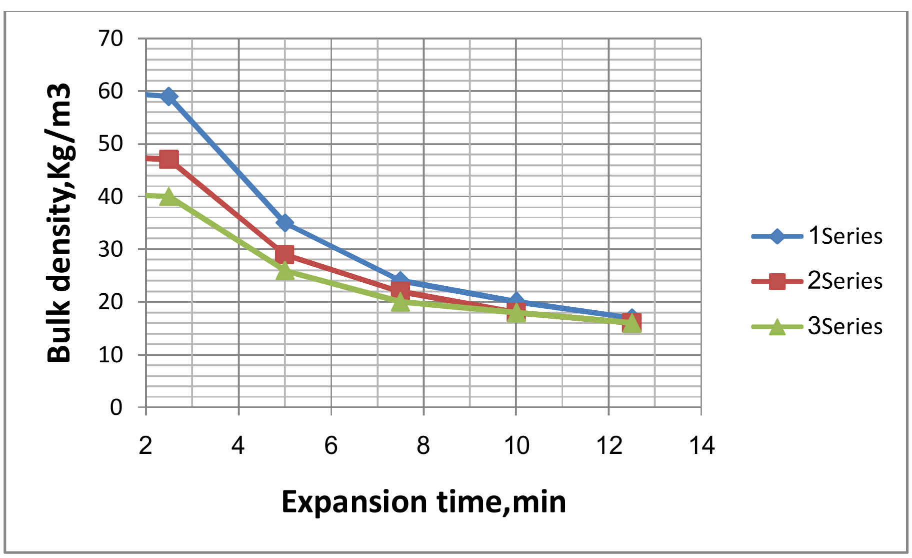

Figure 4-3 Dependence of bulk density from the time of expansion and the initial size of EPS beads. where series1(D =1.0) , series2(D =0.63), series3(D =0.4)

4.3.2. Effect of expansion time on bulk density of EPS:

Figure 4-3 shows effecting of expansion time on the bulk density of EPS at constant pressure P = 1.15 bar, which corresponds to a temperature of 103°C steam. Data shows that the bulk density of EPS significantly depend on the time. With increasing expansion time the density decreases.

For the time t= 20 s bulk density reaches a value about $\rho = 56$ kg/m^3. For expansion times above 60s the effect of time to change the density is getting smaller. The lowest density of 27.6 kg/m^3 of EPS was obtained for the longest expansion time 180 s.

Table 4.2 effect of expansion time on density of EPS at constant pressure P=1.15 bar.

Expansion time (s)	Bulk density (Kg/m^3)
20	56
26	39
34	35
54	29
60	28.5
120	27.9
180	27.6

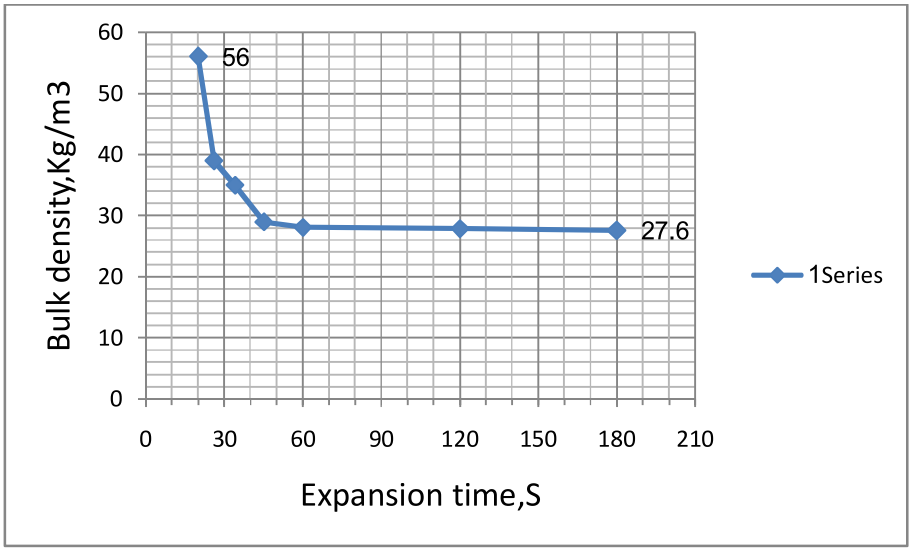

Figure 4-3 effect of expansion time on density of EPS at constant pressure P=1.15 bar

4.3.3. Effect of expansion pressure on bulk density of EPS:

Effect of expansion pressure on bulk density of EPS is shown in Figure 4-4. The study was take for expansion time t = 180 s, because of the lowest density of EPS received. The data is presented in table4-3. From these data it's possible to obtain an EPS density with increasing pressure density decrease. For maximum test expansion pressure P = 1.4 bar (the temperature of the steam is T = 109°C), the density of EPS was obtained ρ = 17, 6 kg/m^3.

Table 4.3 effect of expansion pressure on density of EPS at constant time t=180 s.

Expansion pressure (bar)	Bulk density (Kg/m^3)
1.15	27.2
1.2	26.7
1.25	23.4
1.3	21.6
1.4	17.6

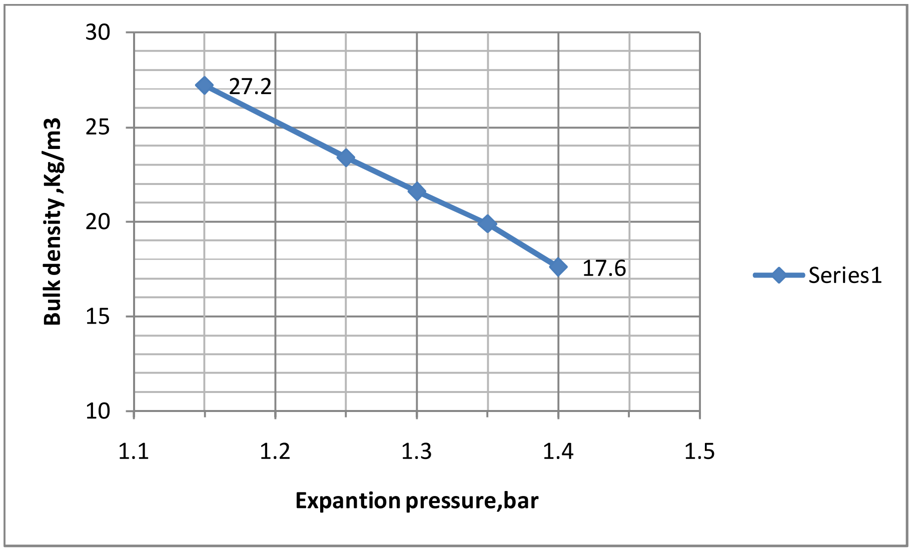

Figure 4-4 effect of expansion pressure on density of EPS at constant time t=180 s

It is known that immediately after expansion as a result of sudden cooling of beads followed by condensation of pentane inside the beads, which causes overpressure inside them. This causes the collapse of beads. In Figure 4-5 EPS beads are presented immediately after expansion. The surfaces of the beads are smooth and their shape is spherical.

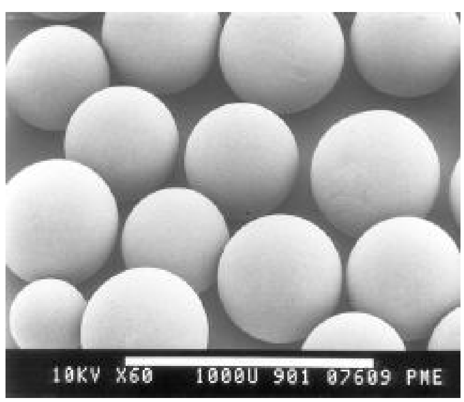

Figure 4-5 Beads immediately after expansion, magnification x60

Source: www.eps-system.com

Chapter Five

CONCLUSIONS AND RECOMMENDATIONS

5.1 The Conclusions of this study are summarized as follows:

- Final density of EPS is determined in pre-expansion process.
- When size of beads increase the bulk density of EPS decreases.
- Analysis of test results confirmed that with increasing of expansion pressure the bulk density of EPS decreases.
- Analysis of test results confirmed that with increasing of expansion time the bulk density of EPS decreases.

5.2 **Recommendations**:

The following recommendation to be study in future

1. Carry out to optimization study to find out the optimum time, pressure for different densities.
2. Performing of more studies to determining other factors effect on density.
3. EPS beads contain a flammable gas, usually pentane**.** Pentane is extremely flammable. Its flash point is minus 50°C and its boiling point 36°C. It is heavier than air; these facts should be recalled when dealing with EPS.

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