

**Development of Polyurethane Batch Foaming Plant for
Small and Medium Foam Production**

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CERTIFICATION

I certify that this project was carried out by **Onamade Akinola Oladele** and has not been submitted elsewhere for publication or the award of a certificate.



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03.10.06

DEDICATION

This project is dedicated to the Almighty God for his grace over my life and to my loving wife.

ACKNOWLEDGMENT

Special thanks to the Almighty God, Alpha and Omega, the beginning and the end of all things for his mercies endureth forever.

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CHAPTER ONE

1.0 INTRODUCTION

Batch foaming machine is a set of equipment arranged in an effective and efficient way for the production of foams. This necessitates a carefully controlled reaction to obtain foam of desired and consistent quality. The individual chemicals are prepared for use in feeding tanks from where they are metered and forwarded to a mixing vessel where they are mechanically mixed together and then dispensed into moulds where the foam formation takes place.

Flexible Polyurethane (PU- foam) being one of the major component in foam production was first introduced for special purposes in the late 1950's (Armstrong, 1980). The materials soon gained interest and common acceptance as a replacement for rubber and fibre materials. Compared with latex foam products, flexible PU-foam is superior in many ways. It can be produced in densities ranging from about 12 to 50kgs/cbm. It has higher tear strength, better resistance to oxidation, aging as well as fire, and its open cell-structures enables it to absorb and emit humidity, e.g. body heat/humidity.

As a result of the ever increasing world population, market demand for foam products increased rapidly, new products and applications were developed and raw materials were improved and diversified accordingly.

This necessitate the expansion of the existing factories and the establishment of new plants in more part of the world. There is now variety of different types of foam available for various applications.

The opening of new market segments, the ongoing introduction of new applications and increasing transportation cost still make it interesting and profitable to expand in the foaming industry in most countries.

It must be concluded, therefore, that foaming industry has proven to be one of the most expanding and profitable light industries in the world and that it may continue to be so for a long time to come.

It should be added also that the investment required for the setting up of a foaming industry is rather low in comparison to most other industries and as such necessitate this project and the returns is quite favourable considering the socio-economic situation in the country.

1.1 OBJECTIVES OF THE PROJECT

The general objective of this project is to develop a batch foaming plant for small scale foam industries. The specific objectives are to:

- 1 Investigate various raw materials for flexible PU-foam production.
- 2 Identify various production techniques available for foaming.
- 3 Develop a general requirement for the setting up of the proposed Industries.
- 4 Design a batch foaming machine for foam production in small and medium scale Industries.

1.2 RESEARCH METHODOLOGY

The search on various raw materials and their properties for foam production was carried out. Visits to some foam manufacturing companies in Nigeria as well as on line research on international companies were embarked upon. Intensive study and analysis of the manufacturing techniques adopted by different companies in foam production in order to

establish basic requirement for small and medium scale foam production were carried out. Design specifications for the foam production, which include the density, maximum shot and block mould dimension, were considered. Also the detailed design parameters for the machine which include the power requirement, volumetric requirement, mixing speed, shaft, base frame for rigidity. The data collected and the design analyses were used to develop locally adaptable polyurethane batch foaming plant as well as the process layout for small scale and medium scale foam production which is now in operation.

1.3 PROJECT SIGNIFICANT

The project is expected to

- (a) enhance the analytical and logical power of the foam manufacturers in the determination of the raw materials requirement for operational take off.
- (b) facilitate the design of a Flexible Polyurethane (PU) batch foaming machine using locally available materials thus assisting the investors in the performance specifications of the machines.
- (c) providing the detailed cost for setting up a batch foaming plant thus creating a cost effective layout for the proposed industry.

CHAPTER TWO

2.0 Literature Review

2.1 History

The origin of polyurethane dates back to the beginning of World War II where it was first developed as a replacement for rubber (Neff and Macosko, 1995). The versatility of this new organic polymer and its ability to substitute for scarce materials, spurred numerous applications. During World War II, polyurethane coatings were used for the impregnation of paper and the manufacture of mustard gas resistant garments, high-gloss airplane finishes and chemical and corrosion resistant coatings to protect metal, wood and masonry.

By the end of the war, polyurethane coatings were being manufactured and used on an industrial scale and could be custom formulated for specific applications. By the mid-50's, polyurethanes could be found in coatings and adhesives, elastomers and rigid foams. It wasn't until the late-50's, that comfortable cushioning flexible foams were commercially available. With the development of a low-cost polyether polyol, flexible foams opened the door to the upholstery and automotive applications we know today.

Formulations, additives and processing techniques continued to be developed such as reinforced and structural moldings for exterior automotive parts and one-component systems. Today, polyurethanes can be found in virtually everything we touch – our desks, chairs, cars, clothes, footwear, appliances, beds, the insulation in our walls, roof and moldings on our homes.

2.2 Batch Foaming Machine

Before the design of a typical batch foaming machine, there is need to note the following:

- The raw materials needed for foam production
- The foam properties and production techniques
- The planned Production
- Plant layout and Building requirements

2.3 Raw Materials for Flexible PU-Foam

The required chemicals are available from a number of suppliers under different trade names, but can be identified in general terms as follows:

2.3.1 Polyol

This is also referred to as "Polyether Resin" or just "Resin". It is the major component in all formulations. Foam formulations are always based on 100 parts by weight (p.b.w.) of Polyol, and the ratio of all other components are calculated on this basis, in accordance with the quality of foam to be produced.

They are typically produced through an alkylene oxide polymerization process. They are high molecular weight polymers that have a wide range of viscosity. Various polyether polyols that are used include polyethylene glycol, polypropylene glycol, and polytetramethylene glycol. These materials are generally utilized when the desired polyurethane is going to be used to make flexible foams or thermoset elastomers (Flory,1953).

2.3.2. T.D.I. (Toluene-Di-Isocyanate)

This is the second major component, and is used at a ratio between approximate 40 to 65 p.b.s.

This ingredient is very toxic, and the manufacturer's safety instructions must be strictly observed at all times.

TDI is produced by chemically adding nitrogen groups on toluene, reacting these with hydrogen to produce a diamine, and separating the undesired isomers. PMDI is derived by a phosgenation reaction of aniline-formaldehyde polyamines. In addition to these isocyanates, higher end materials are also available. These include materials like 1,5-naphthalene diisocyanate and bitolylene diisocyanate. These more expensive materials can provide higher melting, harder segments in polyurethane elastomers (Park and Dymeck, 1996).

2.3.3. Amine Catalyst

It is used at an approximate ratio of 0.10 to 0.60 p.b.w. in order to accelerate gas production.

2.3.4 Tin Catalyst

This is also known as "Stannous Octate" - is used at a ratio of approximate 0.20 to 0.40 p.b.w. in order to improve the cross-linking of cells.

2.3.5 Silicon Stabilizer

This is used at a ratio of approximate 0.70 to 2.0 p.b.w. It is needed to stabilize the cell structure and influence the size of the cells (Decker,1996).

2.3.6. Water

This is essential to initiate the chemical reaction between Polyol and T.D.I., producing carbon dioxide and forming the basic polymer of the foam.

The proportion of water (usually between 2 and 5 p.b.w.) determines the final foam density.

Good quality mains water may be used, but in case of impurities, or highly acid or alkaline water, it is advised to use pre-treated water.

2.3.7 Air

This is used as a blowing agent to achieve an open cell structure, being decisive for coarse or fine cell structure.

Moreover, the following components may be used:

2.3.8. Blowing Agent

Refrigerant, R-11 or Methylene Chloride is used at a ratio of approx. 5-20 p.b.w. as an additional blowing agent in order to achieve low density or soft "feeling". Recently some other blowing agents have been introduced (Luebke, 1998).

2.3.9. Colourants

To be used to produce foams of different colours for quality identification and/or sales attraction.

2.3.10. Flame Retardants

This is required to achieve fire-safe materials.

2.3.11. The Fillers

To achieve special properties and reduce costs. All chemicals are fairly low viscous liquids, and are supplied in bulk tanks, drums, cans or plastic containers. Supply in drum is by far the most common.

2.4 PROPERTIES THAT AFFECT FLEXIBLE POLYURETHANE FOAM PERFORMANCE

2.4.1. Density

This is a measurement of the mass per unit volume. It is measured and expressed in pounds per cubic foot (pcf) or kilograms per cubic meter (kg/m^3). Density is a key flexible polyurethane

foam specification. It is an important indicator of foam performance with regard to comfort, support and durability. It is also an indicator of the relative economics of the foam.

Foam density is not weight. It's actually a measurement of mass per unit volume. Density is a function of the chemistry used to produce the foam, of additives used to increase density, and of any additives used to improve the combustion resistance properties of the foam.

Flexible polyurethane foam is available in a broad range of densities, ranging from as low as 13kg/m^3 to as high as 96kg/m^3 . Most foam applications utilize foam in the 15kg/m^3 to 40kg/m^3 density range. Foam density is a function of the density of the virgin or unfilled foam. This is also called polymer density. If the foam contains no additives or fillers, the polymer density is the same as the overall foam density. When additives or fillers are used in producing the foam, the foam density will be higher than the polymer density. Generally speaking, the higher the polymer density of the foam, the greater the cost of the foam.

However, this foam will generally also have better physical properties including support and durability. If there is a concern for foam performance, it is always important to determine whether the foam contains any type of additives so that the clearest understanding can be established as to whether the foam density and the polymer density are one and the same.

2.4.1.1 How Density Affects Foam Performance

Obviously, the denser the foam, or the more material used to produce it, the more material there is in the cushion to provide support for weight. It is important to remember, though, that foam surface firmness is independent of foam density. High density foams can be produced to be very soft. Low density foams can be made to be very firm.

Therefore, there is no such thing as "hard" or "firm" density. High density foam products generally offer great deal of support, but they may actually be fairly soft foams. The difference

between firmness and support is that Firmness (25% IFD) is a measurement of the surface feel of the foam. Support is the foam's ability to "push back" against weight and prevent the foam from "bottoming out." Higher density foam helps prevent the feeling of having the foam collapse beneath body weight in an end use application. Both firmness and support affect foam comfort. There is even a measurement to determine the foam's ability to provide support. This measurement, support factor, is determined by measuring the firmness (IFD) of the foam by compressing it 25 percent of its original height (e.g., a 4" block of foam to 3") and then measuring the firmness (IFD) when compressing the same foam sample 65 percent. The ratio of the 65 percent IFD divided by the 25 percent IFD is the foam's support factor. If the support factor is good, the ability of the foam to support weight will be highly enhanced. Foams with support factors of 2.0 or above are better suited for load bearing applications, like furniture seat cushions. Density also translates into foam durability. Again, the more polymer material used to produce the foam, the better the foam tends to retain its original properties. The higher the density (polymer or overall foam), the greater will the support factor is. Foam density is independent of the foam firmness.

Support factors can vary in different types of foams. Some "high performance" foam grades are formulated to have higher support factors even at lower densities.

Research into foam durability by measuring flex fatigue, or the loss of foam firmness after flexing the foam by a predetermined number of cycles shows that as polymer density increases, firmness loss is lessened. Less firmness loss means that, for example, seat cushions still feel "new" and that mattress retain their original "feel." Higher density foams also better retain their ability to provide support. Other factors used to gauge foam durability also improve as density increases. One of these is compression set, or the tendency of foam to lose height as it is used. As

density increases, height loss decreases dramatically, this means that the fabric on furniture cushions stays taut and that mattresses don't get body impressions. Infact, many mattress manufactures have increased the densities of their quilting foam during the past few years to reduce instances of body impressions in innerspring as well as foam mattresses.

2.4.1.2 The Role of Foam Additives and Fillers

As noted before, overall foam density can be affected by additives and filling materials used to manufacture different foams. In some cases, additives are used to improve the combustion performance of foams (Decker,1996). Additive requirements to meet this regulation are relatively minor, but they can affect overall foam density. To meet stringent combustibility requirements, greater amounts of additives or filling materials are needed. Additives are used to increase foam density for other reasons. Additives may be used to increase the overall weight of the cushion, which gives the cushion a heavier, more luxurious feel, or additives and fillers can be used to simply increase the ability of the foam to provide support. Various materials are used as additives to increase density. However, it is important to note that while additives may increase density, and in some cases improve support, they may not improve other properties of the foam. Additives can make foams more likely to tear, and can reduce foam durability. This is because additives, since they are not part of the actual foam cellular structure, can act as abrasives that break down foam cell walls, making foam lose more of its original properties through use. Therefore it is important that when you select foams for different applications, you look at the polymer, or unfilled, density of the foam being used.

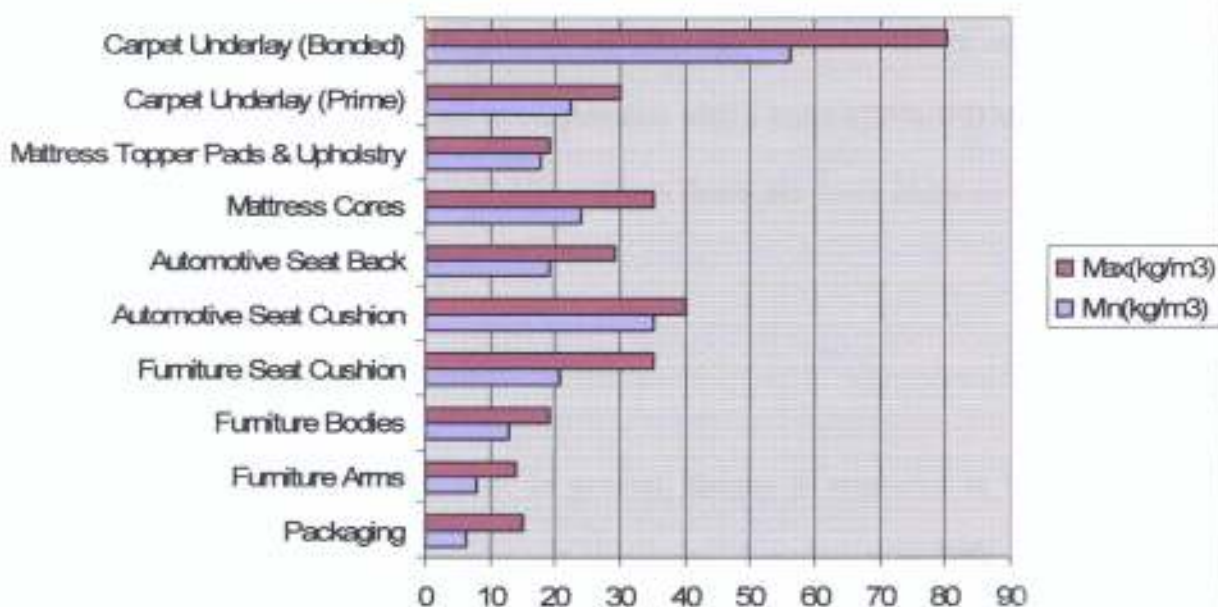
Table 1: Some Starting Formulation for Flexible Foam

Density(kg/m ³)	18	21	23	28	32
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RAW MATERIALS	kg	kg	Kgs	kgs	kgs
Polyol (3000MW)	100	100	100	100	100
TDI (80/20)	55	50	47	42	38
Methly Chloride	6	5	3.6	0	0
Water	3.6	3.2	2.98	2.57	2.2
Silicon Witcol (L580)	1.2	1.0	0.92	0.82	0.72
S.O Witco D-19	0.25	0.23	0.21	0.2	0.21
Amine MAA-11	0.23	0.24	0.24	0.27	0.27
Colours	0.38	0.35	0.3	0.28	0.27
Temperature	22-25 ⁰ C	22-25 ⁰ C	22-25 ⁰ C	22-25 ⁰ C	22-25 ⁰ C

Source: www.foam-machinery.com

Typical Density Range For Different Foam Application



Source: www.pfa.org

Fig 1: Typical Density Range for Different Foam Application

2.4.2 Indentation Force Deflection (IFD)

This is a measure of the load bearing capacity of flexible polyurethane foam. IFD is generally measured as the force (in pounds) required to compress a 50 square inch circular indenter foot into a four inch thick sample, typically 15 inches square or larger, to a stated percentage of the sample's initial height. Common IFD values are generated at 25 and 65 percent of initial height.

2.4.3. Support Factor (Compression Modulus)

Support Factor = 65% IFD, 25% IFD determined after one minute of rest or recovery. When the support factor is known it can be used in conjunction with a known 25% IFD value to determine the 65% IFD value. Seating foams with low support factor are more likely to bottom out under load.

2.4.4. Flex Fatigue (Dynamic Fatigue)

This is a softening or loss of firmness. In general, fatigue is measured in the laboratory by repeatedly compressing a foam sample and measuring the change in IFD. Several different protocols, including methods contained in ASTM, ISO, and BIFMA testing standards, may be used. Even ASTM 3574, one of the more widely used sets of testing standards, contains multiple testing methods. In selecting one or more test methods, it is important to consider the intended foam application and to choose a testing protocol that closely simulates the intended application.

2.4.5. Tear Strength

This is a measure of the force required to continue a tear in a foam after a split or break has been started and expressed in pounds per inch (lb./in.) or kilogram per meter (kg./m.). This property is important in determining suitability of foam in applications where the material is sewed, stapled, or otherwise anchored to a solid substance.

2.4.6. Resilience

This is an indicator of the surface elasticity or "springiness" of foam. It is measured by dropping a steel ball onto the foam cushion and measuring how high the ball rebounds.

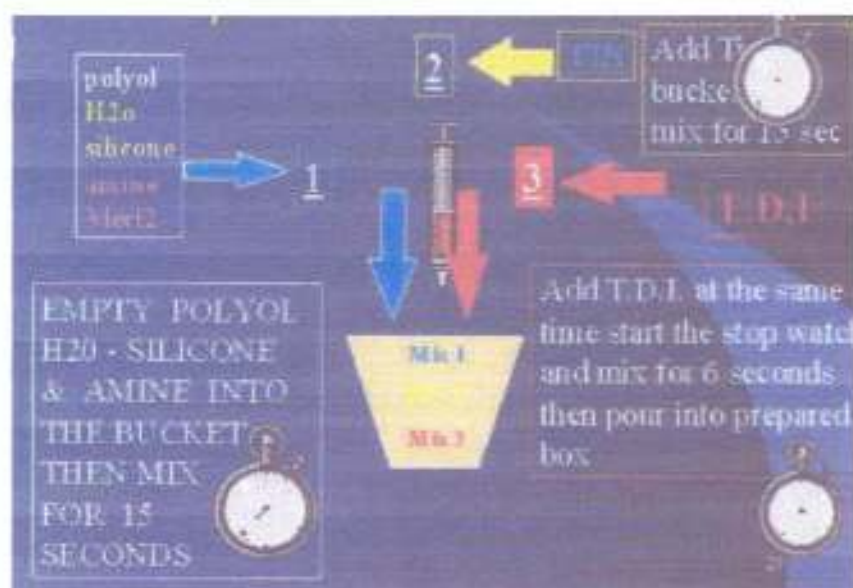
2.4.7. Hysteresis -- Measurement of a foam's ability to maintain original support characteristics after flexing. Normally, the firmness (IFD) is tested at 25% indentation, 65% indentation and again at 25% on the way up. Hysteresis is the percent of 25% IFD loss measure as a compression tester returns to the normal (25% IFD) position after measuring 65% compression. Lower hysteresis values, or less IFD loss are desirable. Current research indicates that hysteresis values may provide a good indication of overall flexible foam durability. Low hysteresis in conventional foam is equal to less IFD loss in durability and fatigue tests.

2.4.8. Air Flow

This is the amount of air expressed in cubic feet per minute ($0.0005\text{m}^3/\text{s}$), that can be drawn through a 2" x 2" x 1" (0.05m x 0.05 x 0.025) foam sample at 0.13m (5-inch) water pressure differential. Air Flow is measured by a test. High air flow equates to very open foam while low air flow tends to be pneumatic. Air flow can be a critical factor in FPF performance depending on the application. For instance, in normal furniture cushioning applications, pneumatic foam with low air flow will have poor durability and high compression sets, regardless of density. However, in packaging foam, foam with minimal airflow may be desirable as a shock absorber, or in medical applications, slow recovery foams are used to improve patient care. Low air flow foams are also used in gasketing applications in air conditioning and heating.

2.5 Foaming Principle

In principle, foam will emerge when the mentioned chemical components are mixed together. Actually, it is the addition of water to T.D.I., which triggers the chemical reaction, which results in foam in a matter of seconds.



Source: www.foambasic.com

Fig 2: Foaming Principle

Obviously a carefully controlled reaction is necessary in order to obtain foam of desired and consistent quality, and various types of equipment have been developed for industrial foam production. Usually the individual chemicals are prepared for use in feeding tanks, from where they are metered and forwarded by pumps or pressure to a mixing vessel, where they are mechanically mixed together, and then dispensed onto a conveyor or into a mould, where the foam formation takes place. After the actual formation of the foam, it needs to cure for several hours before further handling. The curing can be achieved through natural or artificial means (Forces cooling/control pressure).

2.5.1 The Forced Cooling Process

The forced cooling or vacuum cooling process permits the use of high water levels in FPF formulations to achieve low density. The high exotherm developed from the use of high water levels is dissipated before it can cause internal scorch or auto ignition of the FPF. The use of air as the cooling medium is relatively simplistic. The flow of the air through the FPF must be uniform to ensure that no "hot spots" remain in the center of the bun.

Care must be taken with regard to making certain that back up systems are in place in case a power outage or mechanical failure interrupts the cooling process. Timing is also important so that critical physical properties are developed in the FPF and to prevent autoignition. The basic process consists of a series of vacuum plates beneath or a vacuum chamber surrounding the FPF bun that pulls air through it. Hot gases emanating as reaction products, as well as small amounts of volatile impurities or unreacted products, are removed and the FPF is cooled to safe temperatures as the air is drawn through the FPF. Exhaust gases can be treated to remove volatiles before the cooling air stream is discharged into the atmosphere.

Uniformity of physical properties throughout the block is one of the highly desirable advantages of forced air foam cooling.

The reduction of some physical properties in low-density, hard foam may limit the use of all-water in some applications. The use of some chemical additives or small amounts of conventional ABAs can restore the diminished properties.

Experience with the process indicates that formulations and plant equipment can readily be adapted to force cooling.

An unquestioned advantage of forced foam cooling is that total elimination of ABAs is achievable. The concept is not new, but the motivation for its use has changed. The process has

been considered because of its potential for reducing space requirements for curing and storage of FPF.

Now, concerns for the environment inside and outside the plant have spurred research and development. Forced cooling can be used with most other chemical and mechanical methods.

2.5.2 Controlled Pressure Foaming

Controlled pressure or variable pressure foaming is achieved in a totally enclosed chamber either on a batch basis or a continuous basis. This sealed environment prevents the escape of emissions into the plant environment while the emissions to the atmosphere can be carefully controlled and easily absorbed or scrubbed. Reduction of pressure in the chamber permits the FPF to rise higher for a given amount of water contained in the formulation. Thus lower density FPF is readily achieved without the use of ABAs.

Another aspect of controlled pressure foaming is improved quality control. Atmospheric factors such as heat and humidity that affect the mix in more traditional processes do not come into play in the air-tight chamber.

Pouring controlled pressures below and above atmospheric pressure allows the production of existing foams and the introduction of new lower density softer foams as well as higher density firmer foams.

The controlled pressure foaming technology is relatively new, so there is a lot to learn to take full advantage of the process. However, once a formulation is determined to be a match for the variable pressure method, the foam can be produced over and over again with minimal variation.

Conversion of existing FPF production equipment to controlled pressure foaming is not an option. New equipment is required. The cost of a single continuous-operation system is in the multi-millions. Batch systems are limited in production output but are less costly.

2.5.3 Discontinuous Foaming

This is characterized by the use of moulds, being filled one by one, and can be evaluated as follows:

Advantages:

- * Well suited for finished products having complex or odd shapes.
- * Well suited for finished products in combination with other materials (such as seats and chairs with steel tube and spring interiors).
- * Well suited for small-scale production.
- * Flexible production (formulation can be changed from one block to the next).
- * Limited investment.
- * Well suited for special production and tests.
- * Moulds can be customized in size and shape.
- * Block cutting machine not required

Disadvantages:

- * Highly controlled processing is required.
- * Labor- and time-consuming production procedure.
- * Skins on all faces of the block (increased block trimming work).
- * Higher chemical consumption (waste after each shot).
- * Expenditure for polyol and solvent to flush machine after each shot.
- * Not well suited for large-scale production.

2.5.4 Continuous Foaming

Also known as "Slabstock Foaming" is characterized by the use of a moving conveyor onto which the chemical mixture is being dispensed, thereby forming a continuous block, which can then be cut off in required lengths.

Advantage:

- * Continuous method, i.e. large production on same machine settings, thus ensuring consistent quality throughout the production.
- * Well suited for large-scale production.
- * Time- and labor-saving production procedure.
- * Different block-size obtainable, since block width is adjustable.
- * Built-in extra capacity to be utilized inexpensively.
- * Production costs low.

Disadvantage:

- * Not suited for products having very complex or odd shapes, nor together with other materials.
- * Not well suited for very small productions.
- * Requires a block cut-off machine (extra cost).
- * Usually higher investment than Block Moulding.
- * High start and stop costs when limited production volume is required.
- * High cost in case of production failure.

2.6 Planned Production

Certain important preconditions have to be laid down in order to decide how to design and equip a specific foaming factory. It is thus essential to know the following:

- * Planned annual production capacity.
- * Planned finished products divided into groups and their proportion of the total production.
- * Planned types and densities of foam.
- * Required block sizes/widths.
- * Climatic conditions.
- * Planned expansions.

Moreover, there are many other factors, which have to be considered carefully and incorporated in the basic planning of the plant.

2.6.1 Area and Buildings

The factors governing the location and size of a foaming factory are many, and may vary considerably. These include price of real estate, size of intended production, infrastructure and communication facilities, market vicinity and transport routes, personnel matters, potential competition, duty and taxation considerations and many others.

2.6.2 Utilities

2.6.2.1 Electric Power

The total requirement depends very much on the types and extent of production machinery to be installed. It may also be necessary to take power required for air condition units into consideration. It is imperative that the actual foaming process is never interrupted, e.g. by power failures, since it is a continuous process. It may be recommended in some cases, therefore, to install a generating plant at the factory.

2.6.2.2 Water

An ordinary industrial water supply will suffice, since for the foaming process only a few hundred litres of water per hour is required. The water should be reasonably pure, but the requirements are not really strict. If in doubt, a water analysis should be carried out to determine, if additional treatment of the water will be necessary. Water installations for fire safety should be considered, and the amounts of water for this purpose will be much higher than for the total production.

2.6.2.3 Compressed Air

A compressor and perhaps air drying equipment should be installed near the foaming machine.

2.6.2.4 Expansion potential

The experience gained over the last 20 years shows that foaming plants were never built too large, but often without proper expansion possibilities. The increasing demand for PU-foam in most parts of the world especially in developing countries makes it important to consider future expansions when planning the initial plant. Adequate, additional space, electric power installations etc. should, therefore, be planned for future expansion.

2.7 Plant Layout

A foaming factory consists of the following main sections:

- i. Raw Material Storage
- ii. Foam Production
- iii. Foam Curing
- iv. Foam conversion & Finishing
- v. Foam Waste Reclamation

- vi. Product Finish
- vii. Finished Products
- viii. Storage Offices & Personnel facilities

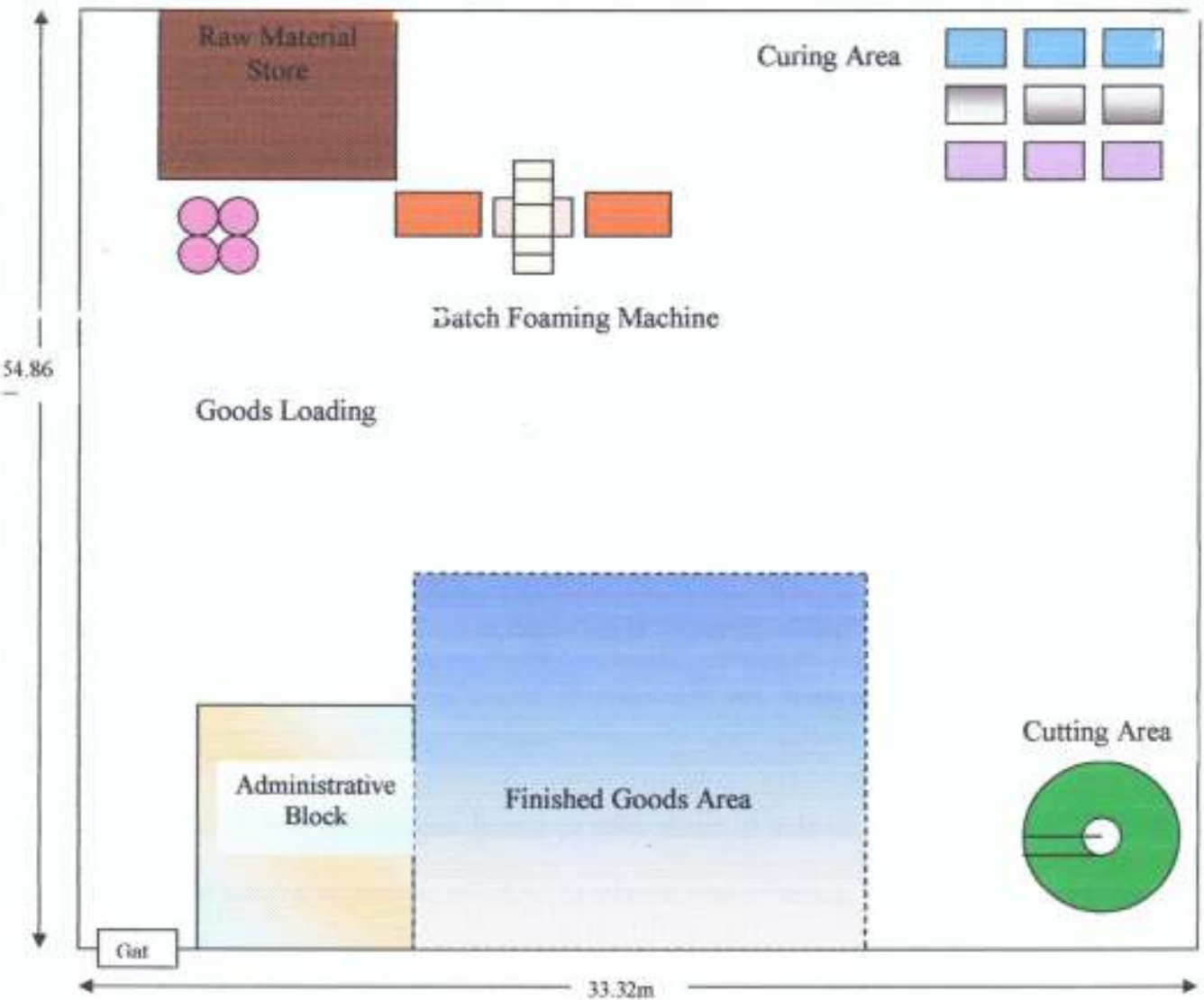


Fig 3: Typical Layout for Foam Plant

2.8 PRODUCTION FLOW

An efficiently operated and successful factory should have a planned production flow line. This reduces handling and storage problems, minimizes labour requirements and increases productivity and profitability. Overcrowded working areas are also inefficient and hazardous.

2.8.1 Handling and Storage

Flexible polyurethane foam is an organic material and is combustible like all organic materials. Organic materials include a wide variety of substances like wood, wool, paper, cotton, nylon, polyester, and polyethylene.

Polyurethane foam, once ignited, can burn rapidly, consuming oxygen at a high rate and generating great heat. Like any other organic material, when it ignites and burns, polyurethane foam liberates smoke containing toxic gases, the primary one being carbon monoxide.

Hazardous gases released by burning foam can be incapacitating or fatal to human beings if inhaled in sufficient quantities. Oxygen depletion in an enclosed space can present a danger of suffocation. Therefore, fire safety is critical in relation to any storage and handling of flexible polyurethane foam.

Foam should not be exposed to open flames or other direct or indirect high-temperature ignition sources such as burning cigarettes, matches, fireplaces, space heaters, forklift tailpipes, welding sparks or bare light bulbs.

Foam is often stored in large quantities. Foam fabricators may keep large blocks of foam in inventory. Finished goods manufacturers may store individual cushions or cores for use in products such as furniture, bedding, packaging, or automobiles. Retailers and wholesalers may

warehouse quantities of slab foam for resale to customers, or in the form of products such as replacement parts or carpet cushion.

As with any combustible material, proper care must be taken with foam to minimize potential fire hazards. Even foams formulated to meet specific flammability regulations will burn, including those foams specifically identified as meeting flammability requirements. Safe and proper storage and handling of the material is essential.

Different business will face different foam storage situations, depending on the amount of foam they use and the manner in which it is stored.

Foam manufacturing and fabrication companies are likely to inventory the largest quantities of flexible polyurethane foam. Depending on the size of a particular manufacturing or fabrication operation, small pieces of foam or large "bun" sections containing hundreds of cubic feet of foam may be stored.

Large amounts of foam represent a significant fuel source for a fire. Flexible polyurethane fires generally tend to create very high temperatures - high enough to damage steel framework of buildings if enough of a fuel load is involved. Once ignited, foam fires can spread rapidly, producing intense heat, dense smoke, flammable liquids, and toxic gases.

Therefore, all areas where significant amounts of foam are stored should have adequate provision against fire outbreak.

In fact, all storage areas for flexible polyurethane foam should be analyzed for three key principles of fire safety:

- **Detection**, by using smoke detectors and/or other devices.
- **Alarm**, to alert people in case of fire, so employees can exit the building and safety crews can respond.

• **Suppression**, via sprinklers, fire extinguishers, fire doors, and other methods.

Foam and fabricated parts should be stored away from fabrication operations, machinery, or other source that has the potential to cause ignition. In some cases, insurance carriers require a fire wall between storage and fabrication areas. Scrap foam should not be allowed to accumulate.

They are frequent but avoidable cause of many fires in manufacturing operations.

Whether performed by employees or outside contractors, these operations are often subject to strict insurance company guidelines, and extreme caution should be taken if heat or sparks could be generated. Welding operation should be avoided around flexible polyurethane foam. Plant supervisors should be notified before welding or cutting takes place, so that proper precautions can be administered. Some foam fabrication processes, such as hot wire cutting, bonding or laminating can also pose potential fire hazards. Caution should be exercised when engaging in the processes.

In certain fabrication processes, potentially dangerous fumes are emitted which should be exhausted through properly engineered ventilation systems.

CHAPTER THREE

3.0 Batch Foaming Plant Design

Batch Foaming plant design and fabrication can be accomplished based on fore knowledge of the processes involved in foam production.

3.1 Design Specification

The following design specifications were used as a guide towards the design of the batch foaming plant. This is based on the general knowledge of foam industry and the properties of the raw materials involved.

- Mixing barrel capacity up to 150kg
- Foam quality of between 10-30kg/m³
- Temperature controlled staging tanks capable of maintaining temperatures between 17^o and 25^o for Polyol.
- Block mould of about 2m X 2m X 1m

3.2 Design Configuration

The design configuration is shown in Fig. 4. It consist of the basic mixing drums which is supported on suitable frames, the three storage tanks for TDI, Polyol and MC as well as piping systems and connections.

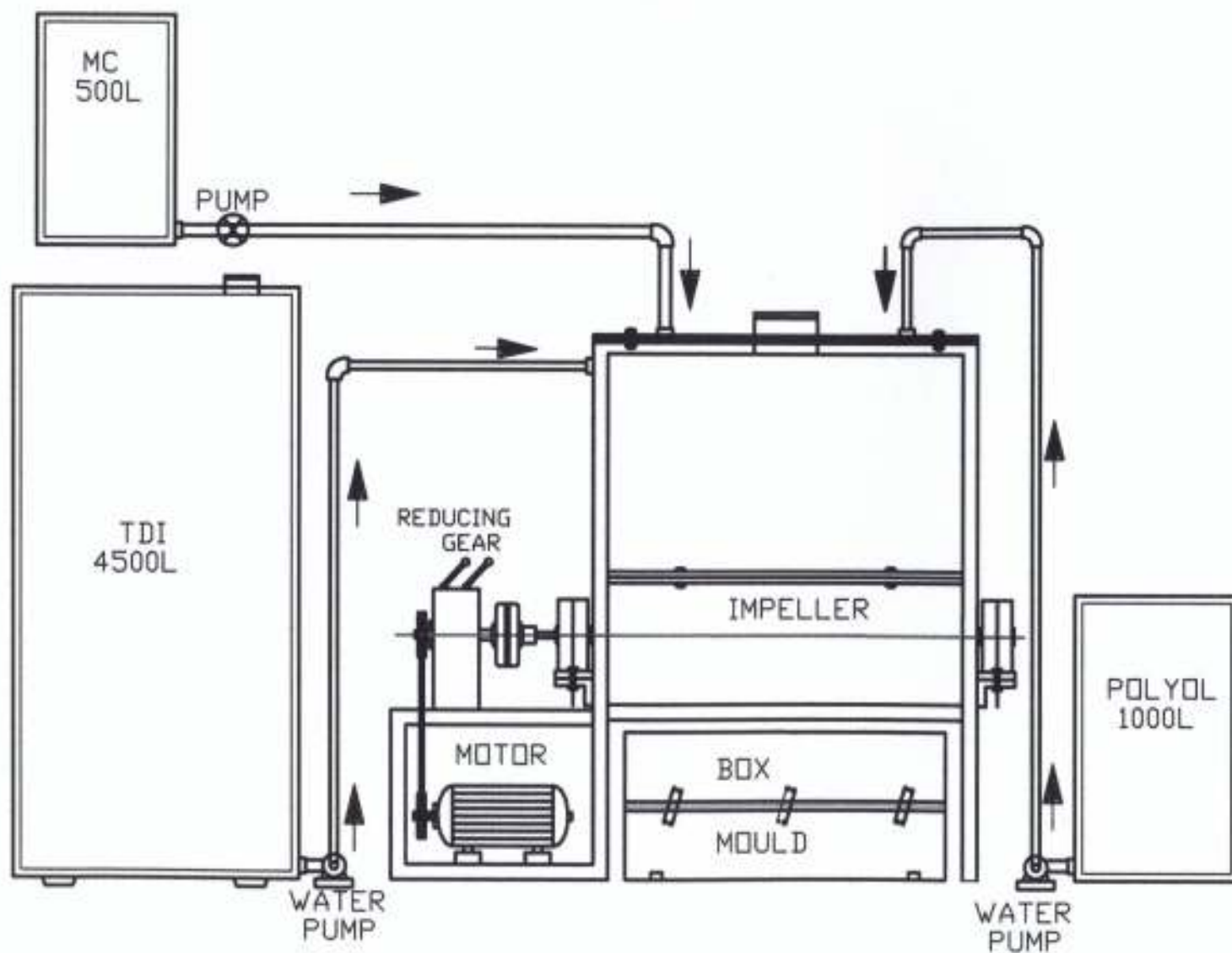


FIGURE 4: BATCH FOAMING PLANT CONFIGURATION

3.3 Mixing Barrel

The mixing barrel, Fig. 5 consists of two halves. The top drum Fig 6(a) a rectangular, well ribbed and securely bolted to a U-shaped lower drum Fig 6(b). The mixing barrel is fitted with double oil seal and inverted bearing assembly to avoid leakages from the barrel. The barrel is to be made of stainless steel or stainless lining. It may or may not be provided with an electric heater depending on the performance of the impeller during testing.



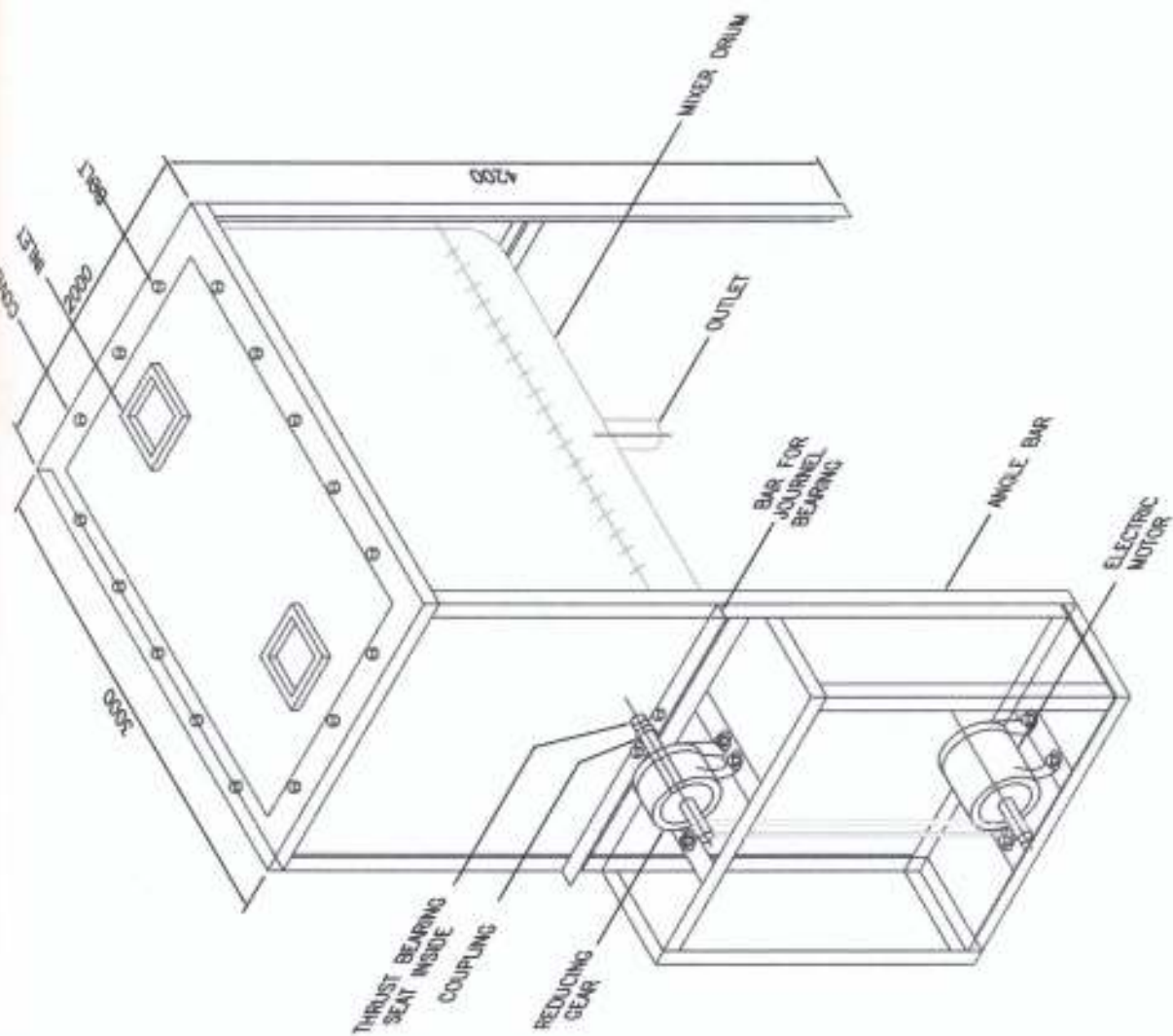


FIGURE 5: MIXING BARREL

3.3.1 Volumetric Design

Using Density $D = 10\text{kg/m}^3$ (Minimum Density)

Mass $M = 150\text{kg}$

Volume $= M/D = 150/10 = 15\text{m}^3$

Considering a mixing barrel of cylindrical base and a rectangular top made with stainless steel for 15m^3 mixing capacity.

The barrel is design for easy clean (split system) gasket covered with access doors hinged parallel to main shaft. The door is to be fitted with safety switch actuated by grate and drive end. The interior is with grit finish, fillet welds and continuous exterior welds brushed and cleaned. The mixing barrel is fitted with double oil seals and inverted bearing assembly to avoid leakage from the barrel.

Volume $= l \times b \times h_r + \frac{\pi d^2 h_c}{8}$

Using

Length $l = 3\text{m}$

Breath $b = 2\text{m}$

Diameter $d = 1.25\text{m}$

Cylindrical Height $h_c = 3\text{m}$

Then

$h_r = 1.7\text{m}$

3.3.2 Impeller Design

Tank height = 1.7m + 0.75m (Rectangular height + Cylindrical base height)

Tank breath/width = 2m

The selected tank diameter/width is 2m

While the height is 2.45

Using equation established by Bidsack and Fasig (1951)

$$1.5 < T_d < 2.5D$$

where

D = Impeller disc diameter

T_d = Tank diameter

$$T_d = 2.5D$$

$$D = 2/2.5$$

$$D = 0.8m$$

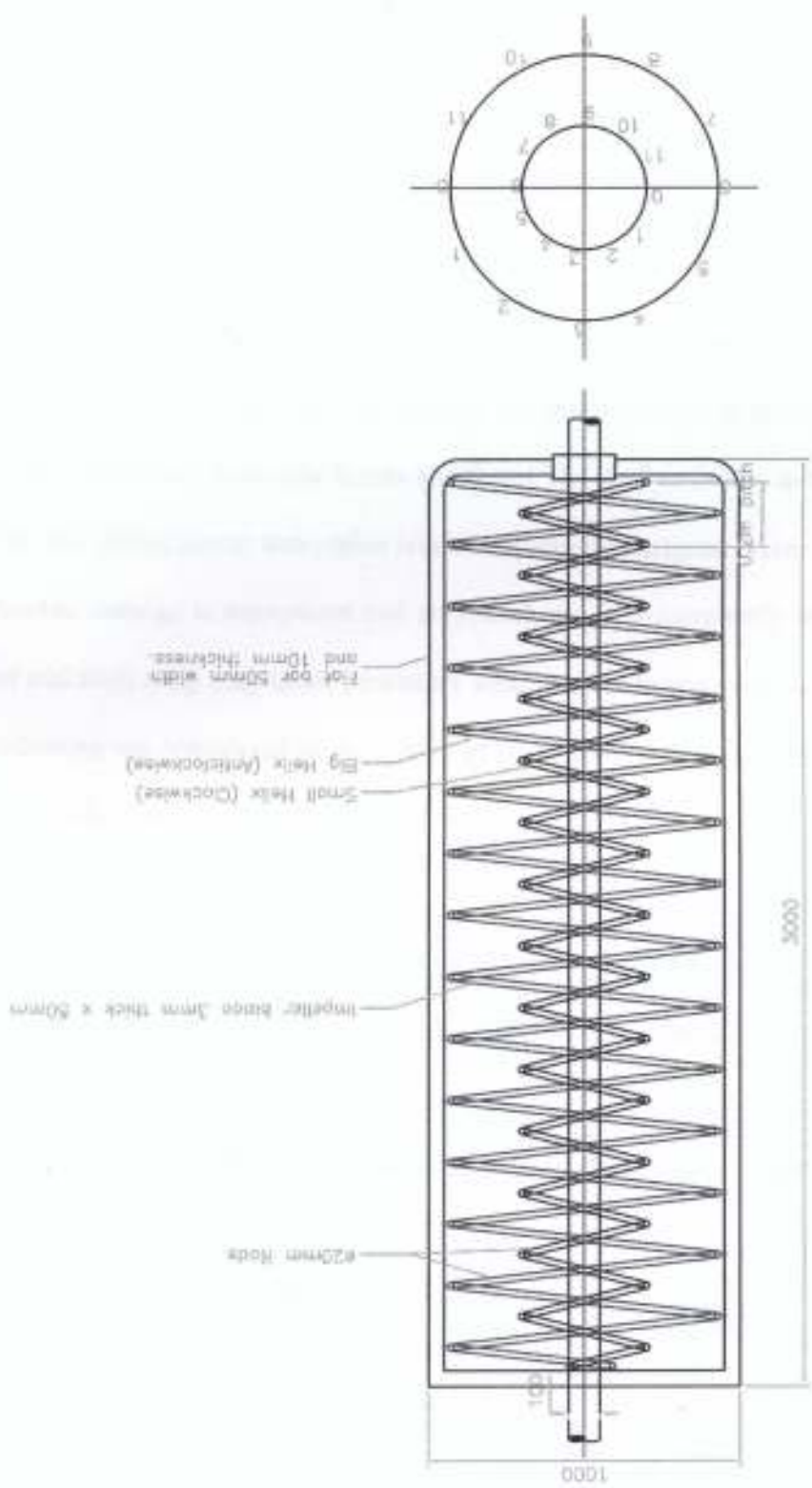


FIGURE 7: IMPELLER DESIGN

3.3.3 Power Requirement

A 5HP 3-phase motor is expected to drive the impeller through a set of pulley connected to a shaft mounted gear reducer providing between 39 to 60rpm output drive. A varying gear speed is required to achieve certain mixing quality.

3.3.4 Shaft Design

Mixer shaft are required to transmit the power from the mixer drive to the impeller(s). With the transmission of this power, the shaft handle the loads occurring including the transmission of torque, moment due to hydraulic forces and thrust The shaft is design to be stiff enough to limited vibration and deflection to acceptable levels. Improperly designed mixer shaft may fail and cause catastrophic damage to equipment and personnel and if is marginally undersized, the excessive run out and shaft whip may cause premature wear to drive bearing and seals.

The following are considered in the design of shaft; tank shape, cross flow in the tank, presence of settling solids (Shigley and Mischke, 1989)

Shaft Strength:

Shaft diameter are selected with the shear stress due to torsional and bending moment not exceed 6000 psi. Bending moment is the product of maximum, unbalanced fluid forces and the shaft length

Unbalanced fluid forces $F = (2000 \times \text{Output HP} \times \text{Position Factor} \times 12) / (\text{RPM} \times \text{Shaft dia})$

Torque $T = (63025 \times \text{Output HP}) / \text{RPM}$ (Ogedengbe and Aderoba, 2002)

Critical Speed:

Critical speed is the first harmonic of the mixer system and can be calculated from handbook data.

Shaft diameters are selected with the operating speed equal to or less than 65% of the critical speed. The vibration amplitude of the shaft, which is static deflection times the stress magnification factor (f_{sm}) must be held to a minimum

f_{sm} is proportional to

$$1/(1-N^2/N_c^2)^2$$

where N = operating speed (RPM)

N_c = critical speed (RPM)

Shaft deflection is given by

$$d = FL^3/3EI$$

where d = shaft deflection at impeller

F = force exerted on the shaft

L = shaft length

E = Young's modulus

I = Moment of inertia

3.3.5 Mixing Head

This design features two mixing chambers perpendicular to each other in an "L" shape. The material components counter impinge in a small horizontal chamber and are forced into a larger chamber from where they exit. The 90° change in direction results in further component mixing and slows the material velocity, resulting in a laminar discharge.

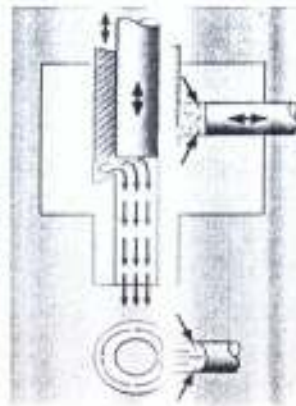


Fig 7: Mixing Head Schematic

Source: www.foam-machinery.com

For this project, the mixing head design can be an area for future development. The purpose is to minimize personnel contact with the mixture and to give better mixing.

3.4 TANKS

The tanks for TDI (4.5m³) Fig 8, Polyol (1m³) Fig 9 and Methyl Chloride (0.5m³) Fig 10

All tanks are be equipped with level gauges, thermometers, safety valves, manholes, drain valves/strainers and conditioning jackets while stirrers is included in the TDI tank to keep the temperature uniform.

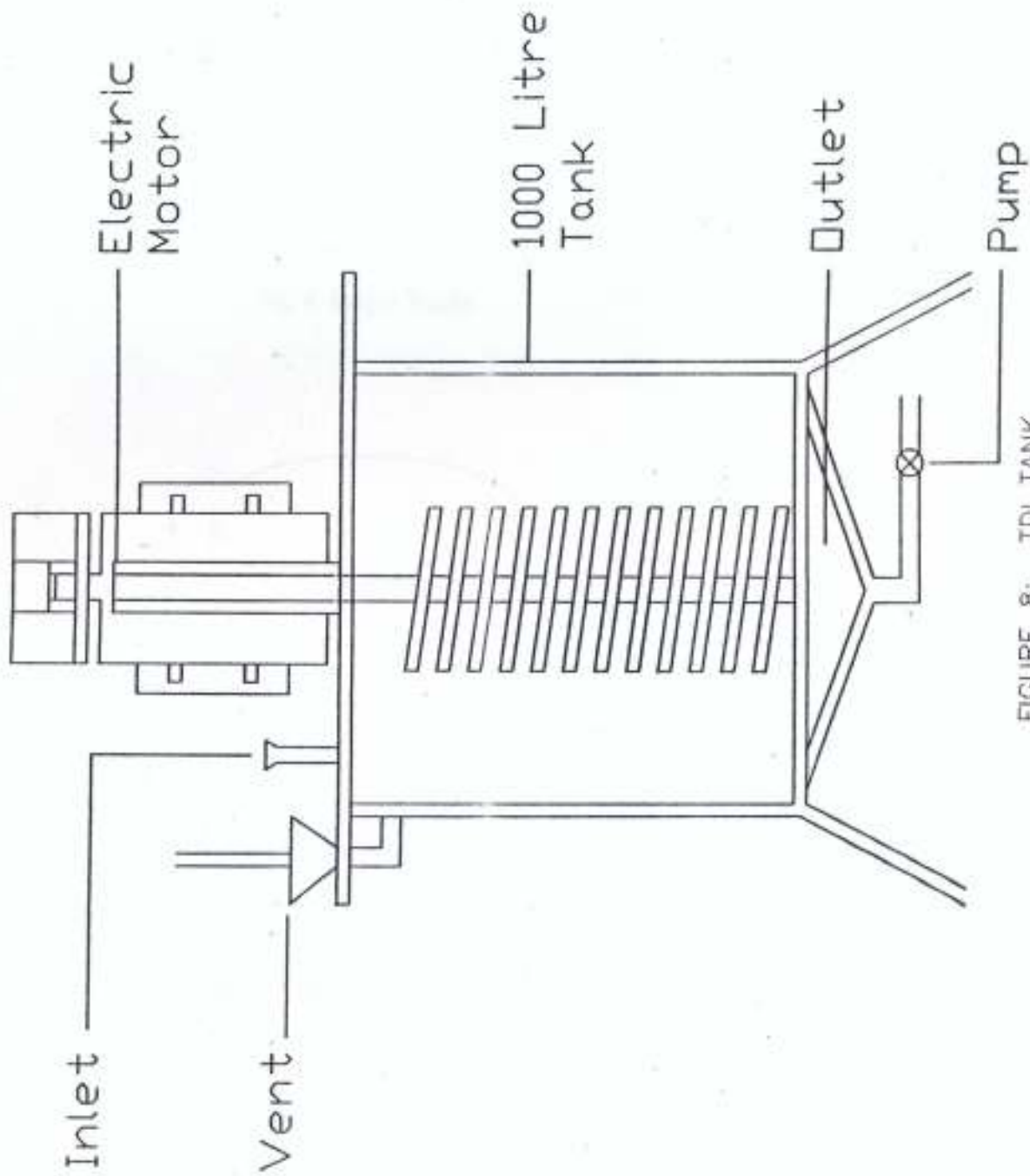


FIGURE 8: TDI TANK

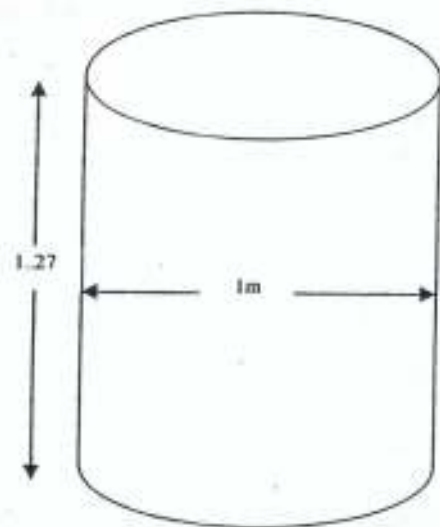


Fig 9: Polyol Tanks

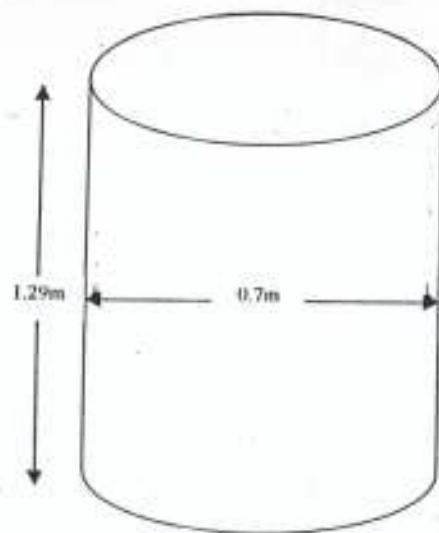


Fig 10: Methyl Chloride

3.5 FOAM DEFECTS

The following are common defects in foam production

	DEFECTS	SOLUTION
1	Boiling	Check silicon Quality and Output Check Tin Quality and Output
2	Collapse	Check Silicon Quality and Output Check Tin Quality and Output Check for Errors in Metering Look for Possible Contamination of Chemicals.
3	Crazy Balls	Low pressure machines: Increase mixer speed High pressure machines: Increase mixing head pressure
4	Smoking	Look for error in metering of the chemicals especially T.D.I, POLYOL and WATER
5	Moon Craters	Lower Mixer speed Increase Tin catalyst/ Lower Amine provided that the foam cells are open enough. Check silicon quality

6	Slow Curing	Increase Amine Increase Tin Look for errors in metering of water or TDI or Polyol or Tin
7	Odour	Try another amine Give the foam time to breath
8	Tacky Foam Surface	Increase catalyst levels (Tin/Amine)
9	Shrinkage	Decrease Tin Decrease Silicon Increase Mixer Speed Check Air Nucleation Check for contamination of system
10	Poor Tensile Strength	Check T.D.I./Water and POLYOL Output Reduce Cell Size

Source: www.polymetric.com

3.6 QUALITY CONTROL

To ensure the quality of the polyurethane material, producers should monitor the product during **all phases of production. These inspections begin with an evaluation of the incoming raw materials by quality control chemists. Test various chemical and physical characteristics using**

established methods. Some of characteristics to be tested should include the pH, specific gravity, and viscosity or thickness. Additionally, appearance, color, and odor should also be examined. Manufacturers have found that only by strictly controlling the quality at the start of production can they ensure that a consistent finished product will be achieved.

After production, the polyurethane product should be tested. Polyurethane coating products are evaluated in the same way the initial raw materials are checked. Also, characteristics like dry time, film thickness, and hardness should be tested. Polyurethane fibers should also be tested for things such as elasticity, resilience, and absorbency. Polyurethane foams should be thoroughly checked to ensure they have the proper density, resistance, and flexibility.

CHAPTER FOUR



4.0 PLANT CAPACITY DETERMINATION

Different industries require different input. Industries are better located where these inputs are readily and cheaply available. Factors that influence location of the Batch Foaming Plant includes access to power supply, communications, labour supply, distance to market where the goods are sold, grants and financial incentives from governments/banks, nearness to raw materials and other infrastructural facilities. All the above mentions factors determines the production cost which in turn affects the principle of demand and supply

With a good location, the following plant parameters and annual production targets are achievable.

4.1 PLANT CAPACITY PLANNING

Plant Parameters

Block/hour	10
No of Shift	1
Block per day (8hrs shift)	80
Block/month	1,760
Planned Annual Production	21,120
Land areas m ²	1,828
Factory Covered Area m ²	1,672

Output Analysis

Planned Annual Production (Block 2x2x1)	21,120
Block (2mx2mx1m) = 92kg (23kgm ³)	
Daily Production (Block)	80
Output per Day (kg)	7,360
Output per Month	161,920
Output per Year	1,943,040
Output per Month (Less 30% down time)(kg)	113,344
Output per Year/ (Less 30% down time)(kg)	1,360,128

4.2 RAW MATERIAL PLANNING

Based on the above data, the analysis below shows the required raw materials per annual for a density of (23kg/m³)

Average Density (23kg/m ³)	Annual Raw Materials	Annual No of Drums	Current Price/ Drum	Total material Cost (NGN)
100.00	876,088.89	4,171.85	128,800	537,334,518.52
47.00	411,761.78	1,647.05	149,500	246,233,543.11
0.24	2,102.61	10.01	80,500	806,001.78
0.21	1,839.79	7.36	69,000	507,781.12
0.92	8,060.02	38.38	75,900	2,913,120.71

3.60	31,539.20	126.16	110,400	13,927,710.72
				801,722,675.96

4.3 AVERAGE PRICE PER KILOGRAM

An average density is taken from 18kg/m^3 (D1), 23kg/m^3 (D2), and 32kg/m^3 (D3) to get the foam price per kilogram using the data in Table 1.

S/N	Raw Materials	Density 1 (18kg/m^3) D1	Density 2 (23kg/m^3) D2	Density 3 (32kg/m^3) D3
1	POLYOL (polyester Resin)	100.00	100.00	100.00
2	TDI (Toluene-Di-Isocyanate)	55.00	47.00	38.00
3	Amine Catalyst	0.23	0.24	0.27
4	Tin	0.25	0.21	0.21
5	Silicon Stabilizer	1.20	0.92	0.72
6	Methyl Chloride (Blowing Agent)	6.00	3.60	0.00
	Others			
7	Water	3.60	2.98	2.20
8	Colourant	0.38	0.30	0.25
9	Air			
		166.66	155.25	141.65

The batch foaming plant is designed for 150kg maximum shot. Adopting the above formulation

to suit the plant design. The following data are arrived at

	Raw Materials	Quantity Required D1	Quantity Required D2	Quantity Required D3
1	POLYOL (polyester Resin)	90.00	96.62	105.89
2	TDI (Toluene-Di- Isocyanate)	49.50	45.41	40.24
3	Amine Catalyst	0.21	0.23	0.29
4	Tin	0.23	0.20	0.22
5	Silicon Stabilizer	1.08	0.89	0.76
6	Methyl Chloride (Blowing Agent)	5.40	3.48	0.00
	Others			
7	Water	3.24	2.88	2.33
8	Colourant	0.34	0.29	0.26
9	Air			
		150.00	150.00	150.00

S/N	Raw Materials	Price/Quantity D1(NGN)	Price/Quantity D2(NGN)	Price/Quantity D3(NGN)
1	POLYOL (polyester Resin)	55,202.21	59,259.26	64,948.82
2	TDI (Toluene-Di- Isocyanate)	29,602.18	27,155.56	24,063.54
3	Amine Catalyst	79.35	88.89	109.60
4	Tin	62.10	56.00	61.38
5	Silicon Stabilizer	390.36	321.27	275.57
6	Methyl Chloride (Blowing Agent)	2,384.74	1,536.00	-
		87,720.94	88,416.97	89,458.90
	Others			

- 7 Water
- 8 Colourant
- 9 Air

Average Price/Quantity	88,532.27
Price Per Kg	590.22

Raw Materials Cost Analysis

Average Cost/kg	590.22
Add on Cost (12% of gas loss and less skin per kg)	88.50
Total Cost per Kg	661.05
Total Cost per Month	74,926,051.20
Total Cost per Year	899,112,614.40

4.4 FOAM PRICE DATA

Foam Size	Vita Foam	Winco Foam	Mouka Foam	Average Price/Size (NGN)	Volume (m ³)	Foam Weight (23kg/m ³)	Average Price/Kg (NGN)
6 X 6 X12"	21,000.00	20,000.00	20,400.00	20,466.67	1.00	23.00	889.8551
6 X 6 X10"	18,000.00	16,800.00	17,000.00	17,266.67	0.84	19.32	893.7198
6 X 6 X8"	15,700.00	14,700.00	15,000.00	15,133.33	0.67	15.41	982.0463
6 X 4.5 X12"	13,200.00	13,000.00	13,500.00	13,233.33	0.75	17.25	767.1498
6 X 4.5 X10"	11,500.00	10,500.00	11,200.00	11,066.67	0.63	14.49	763.7451
6 X 4.5 X8"	9,000.00	8,600.00	8,800.00	8,800.00	0.50	11.50	765.2174
6 X 2.5 X6"	5,000.00	4,500.00	4,500.00	4,666.67	0.21	4.83	966.1836
6 X 2.5 X4"	3,800.00	3,200.00	3,300.00	3,433.33	0.14	3.22	1066.253
6 X 2.5 X3"	2,900.00	2,600.00	2,800.00	2,766.67	0.11	2.53	1093.544
Average Market Price per Kg (NGN)					900.00		

4.5 Total Annual Cost

Total Estimated Machine Fabrication Cost	4,228,000.00
Total Estimated Annual Raw Materials Cost	899,112,614.40
Total Estimated Annual Running Cost	89,911,261.44
Sub-Total	993,251,875.84
Bank Interest (15%)	148,987,781.38
	1,142,239,657.22
Total Annual Sales	
Total Estimated Annual Sales	1,224,115,200.00
Net Annual Profit	81,875,542.78
Net Monthly Profit	6,822,961.90

4.6

DISCUSSION

The raw materials requirement for the foam production carried the bulk of the capital for the start up. The analysis above is very conservative but more income can be realized from the sales of foam waste products such as foam skins, malformation and other defect products which can as well be use as running cost. Also bulk purchase of the raw materials will have great effect on the monthly profit. Most importantly is the foam density which determines the price of the foam. Foam with higher density, has higher selling price which impact positively on the profit.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

A research on the development of the batch foaming plant has been embarked upon. The objectives of the research have been realized. Though the analysis shows a huge amount of money for capital start up, the bulk of the finance is for raw materials purchase. For Small Scale production, the materials purchase can be limited to the available fund while Medium Scale production can seek financial backing from Financial Institution. From the final analysis, it could be inferred that the profit is enormous and the investment is minimal provided the product quality is given utmost priority and the equipments developed locally.

5.2 RECOMMENDATIONS

The importance of foam in our society cannot be overemphasized due to its astonishing benefit to mankind. The market for foam products keeps expanding day by day and thus necessitates the development of a cost effective and efficient batch foaming plant. The PU foam is strongly recommended for small and medium scale production and investors are assured of the returns within the shortest possible time.

Further research work on the development of the mixing head is therefore recommended to minimize personnel contact with the mixture and to improve the mixing quality.

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CATALOGS/Polyurethane-Foaming-Machines/BALAJI-POLYMECH-INDUSTRIES.html

APPENDIX A

FLEXIBLE POLYURETHANE FOAM GLOSSARY

Acoustical Flexible Polyurethane Foam Foam designed to be attenuated (dampen sounds), or be nonattenuated (transmit sound as in loud speakers).

Additive A material used to modify the properties, processing, or end use of a base polymer. The amount of additive used is usually expressed in parts per hundred (by weight) of the total resin in the polymer formulation.

Air Flow Amount of air expressed in cubic feet per minute, that can be drawn through a 2"x 2"x 1" foam sample at .5-inch water pressure differential. Air Flow is measured by a test (ASTM D3574).

Air Traps Voids in molded foam parts caused by encapsulation of air pockets during mold fill-out. These voids have smooth, shiny surfaces.

Amine A class of compounds used as catalysts in polyurethane foam reactions. Amines are characterized by having N, NH or NH₂ groups in the molecule.

Antioxidants Materials which when added to a flexible polyurethane foam formulation improve the resistance of the foam to oxidative type reactions, such as scorch resulting from high exothermic temperatures.

Anti-Static Flexible Polyurethane Foam Foam that contains electrically conductive materials to prevent static electricity buildup or promote static discharge. It is used primarily in packaging applications, such as for electronic components.

ASTM American Society For Testing and Materials An organization devoted to the establishment of standard methods and procedures for testing materials in the United States.

Auxiliary Blowing Agent (ABA) An additive used in the production of foam which supplements the primary blowing agent (water), and can be used to make foam softer or lighter. Compounds used to produce gases to expand, or blow, flexible polyurethane foam during production. Auxiliary blowing agents are low temperature boiling solvents, such as methylene chloride, acetone, hydrochlorofluorocarbons, and isopentane.

Ball Rebound A test procedure (ASTM D3574) used to measure the surface resilience of flexible polyurethane foam. The test involves dropping a steel ball of known mass from a predetermined height onto a foam sample. The rebound height attained by the steel ball, expressed as a percentage of the original drop height, is the ball rebound resilience value.

Basal Cells Larger, irregular cells found just under the surface skin of a molded foam part.

Blowing The process by which flexible polyurethane is foamed during production. In all cases, blowing occurs when water and TDI react to form CO₂. [Also see Auxiliary Blowing Agent (ABA).]

Board Foot A unit of foam measurement equal to a square foot of material one inch in thickness.

Board Stock Flat sheets of flexible foam cut from large blocks or buns of foam.

Boardy Flexible polyurethane foam with a stiff or rigid feel, generally indicated by high 25% IFD values and low compression modulus.

Bonded Foam Flexible polyurethane foam particles or shredded flexible polyurethane foam (often manufacturing scrap) that has been glued to form a useful product. The resultant foam block is "peeled" into the desired thickness. Largest use is for carpet cushion. [Also see Rebonded Foam.]

Bonding The combination of two or more components into a composite. Foam is often adhered to other foam grades or to polyester fiber.

Boston Chair Test Boston Fire Department test method to measure performance of flexible polyurethane foam padding materials when exposed to a fairly severe flaming ignition source. This test is a full scale composite test. Test method is now similar to California TB 133.

Bottom Out Lack of support under full weight load. This characteristic is often found in low-density foam. This term is very subjective, as a foam may bottom out with a heavy person, and be very comfortable to a lighter-weight individual. The problem can be reduced by specifying foam with higher density and/or greater compression modulus value.

Buffed Flexible polyurethane foam pieces that have been shaped or contoured by removal of foam using abrasives.

Bun A segment of foam cut off from continuously produced slabstock type of foam.

California Technical Bulletin 133 (TB 133) A composite test to determine the combustion performance of a complete furniture construction "system". This is designed to be an evaluation of furniture performance when exposed to a large ignition source. The composite test evaluates total furniture construction rather than foam, fabrics, fiber or other construction components on an individual basis.

Catalyst A chemical that changes the rate of reaction of a chemical process, but is not consumed or produced during the reaction. (Catalysts are required for foam production to balance rates of competing reactions and to attain desired physical properties.)

Cell The cavity remaining in the structure of flexible polyurethane foam surrounded by polymer membranes or the polymer skeleton after blowing is complete.

Cell Count The number of cells per linear inch or centimeter, expressed as pores per inch or pores per centimeter.

Cell Opening In foamed materials, the breaking of membranes within the cell structure, permitting flow of air through the material.

Cell Size The average diameter of the cells in the final flexible polyurethane foam product, often measured in micron units.

CFC-Free Foam Flexible polyurethane foams that have been made without the use of chlorofluorocarbons as auxiliary blowing agents.

Compression Force Deflection (CFD) A measure of the load bearing ability of a foam. It is the force exerted against a flat compression foot larger than the specimen to be tested. The value can be expressed at 25%, 40%, 50%, and/or 65% compression (ASTM D3574). Note: previously called "CLD (Compression Load Deflection)".

Clickability The ability of a flexible polyurethane foam to recover from the pinching effects of die-cutting.

Closed Cells Foam cells having intact cell membranes thereby reducing or eliminating passageways for airflow.

Closed Pour The case in molded foam production in which the mold lid is closed and locked and the foaming mixture is introduced through one or more special ports in the lid of the mold.

Coarse Cells Large cells averaging 20 to 30 cells per lineal inch or fewer.

Cold Molding Molding process for the production of high-resiliency foam in which the foam is cured at or near room (ambient) temperature. Pouring is carried out without adding heat.

Colorant Dyes or pigments added to impart color to the final foam.

Combustion Modified Foam Flexible polyurethane foams manufactured by using additives based on chlorine, bromine, and phosphorus chemistry to reduce ease of ignition. Hydrated alumina or melamine is also used.

Combustion Modifying Additive A material that, when added to flexible polyurethane foam, will cause the foam to be more difficult to ignite or burn less rapidly or lose less weight during a fire than without that material. [Also known as "Fire Retardants".]

Comfort The ability of the cushioning structure to deflect at the surface and to conform to body shape, preventing a concentration of pressure on the body without bottoming out.

Compression Modulus Ratio of a foam's ability to support force at different indentation (or compression) levels. It is determined by taking the ratio of the foam's IFD at 25% indentation and 65% indentation (65% IFD/25%). The compression modulus is typically a function of foam chemical formulation and the manufacturing process. In most cases, the higher the density the greater the compression modulus. Other terms that are used interchangeably are: support factor, and modulus. The PFA recommends that compression modulus or support factor be used when referring to foam support properties.

Compression Set A permanent partial loss of initial height of a flexible polyurethane foam sample after compression due to a bending or collapse of the cell framework within the foam sample. A high value of compression set will cause a flexible polyurethane foam cushion to quickly lose its original appearance with use, leaving its surface depressed or "hollowed out". Compression set is measured in the lab by compressing a foam sample 90% of its thickness (or down to 10% of its original thickness) and holding it at 70 degrees C (or 158 degrees F) for 22 hours. Compression set is most commonly expressed as a percentage of original compression. Other deflections, times, and temperatures can be used.

Conventional Flexible Polyurethane Foam Polyether type polyurethane foams made by the basic manufacturing process without polyol modifiers or other additives.

Convolute A foam fabrication process involving the use of a special cutting equipment to produce a foam sheet with dimples. The base under the dimples can be varied in thickness. Peaks can be produced from 1/2" to over 4" in height. Foam dimples can be produced in a number of shapes including egg-like designs, waves, squares or sharply-defined points.

Core The internal portion of foam, free of any skin.

Core Density The density of the foam sampled without skin, glue lines or compressed sections at or near the center of the final foamed shape.

Crushing Usually a mechanical or vacuum-assisted procedure to open the closed cells of a high resilience slabstock or molded foam.

Cure A term referring to the process whereby chemical reactions approach completion. At 100% completion, a foam should have 100% of the physical properties attainable with that particular formulation.

Cure Time The length of time required for sufficient reaction completion to develop a desired level of polymer strength and dimensional stability and to attain ultimate physical properties.

Dead Foam Foam that has a low resiliency and only slowly regains its original shape after deformation.

Deflect To compress, usually by a specified amount or percentage.

Demold Time The time between the discharge of the foam ingredients from the mixing head and the time at which a molded object may be removed readily from the mold without tearing or altering its shape and without post-expansion.

Densified A material that has been made more dense by permanently compressing a unit mass into a smaller volume.

Density A measurement of the mass per unit volume. It is measured and expressed in pounds per cubic foot (pcf) or kilograms per cubic meter (kg/m³) (Test Method ASTM D3574).

Die Cutting The "stamping out" of foam into parts, useful for long runs of cut parts requiring consistency in size.

Discoloration The gradual yellowing of foam due to a photochemical reaction. It is faster in sunlight than in artificial light, although it occurs in both. Fresh foam may discolor in the center of the block as a result of thermal or chemical events. (Does not affect physical properties.)

Dish Description of what occurs when a weight is placed on the center of a cushion or mattress and the corners rise up in response.

Durability As applied to flexible foams, the term refers to how well a foam retains its load bearing capacity and shape with use. Most measures of durability are done with laboratory-scale tests.

Dynamic Fatigue A durability test performed in the laboratory using roller-shear or pounding type mechanisms. A roller, longer than the foam width, is rolled back and forth across the foam. The roller is mounted in an offset position to impart a shearing action. (ASTM D3574).

Elastomer Polymers which resist and recover from deformation produced by force, similar in behavior to natural rubber.

Elephant Skin Surface creasing effect due to lateral resistance of a stiff, thick flexible polyurethane foam when compressed parallel to its face.

Elongation The percent that a specially shaped sample will stretch from its original length before breaking. (Test Method ASTM D3574).

Exotherm The heat released as a by product of some chemical reactions. All flexible polyurethane foam production reactions are exothermic.

Fatigue (Flex Fatigue) A softening or loss of firmness. Fatigue can be measured in the laboratory by repeatedly compressing a foam sample and measuring the change in IFD.

Filled Foam The addition of inorganic materials such as marble dust, barium sulfate, silica or clay, in foam to increase the density. Fillers are often added to increase the Support Factor. Filled polyurethane foam may be inappropriate for some applications, if the polymer content of the filled foam is not sufficient for the intended application before fillers are added. The fillers are not chemically bonded into the foam polymer. They are instead mechanically trapped within the molecular structure of the polymer. Filled foams with low polymer content or a high percentage of filler material tend to have less strength and durability.

Fine Cells A term used to describe foam with a cell count of 80 or more per lineal inch.

Fingernail Test A subjective test to determine the recovery of flexible foam when it is indented with a fingernail or sharp object.

Fire Retardants A material that, when added to flexible polyurethane foam, will cause the foam to be more difficult to ignite or burn less rapidly or lose less weight during a fire than without that material. [Also known as "Combustion Modifying Additives".]

Flame Lamination The practice of bonding flexible foam to a fabric or other material (film, etc.) by melting one surface of the foam with a flame source and quickly pressing it to the other substrate before the melted material resolidifies. [Also called Flame Bonding.]

Flex Fatigue The loss of foam firmness after flexing the foam a predetermined number of cycles.

Foam A lightweight cellular material resulting from the introduction of gas bubbles into a reacting polymer.

Formulation The list of chemicals and their relative amounts to be used in the preparation of a foam.

Friable A term used to indicate the crumbling, flaking, or powdering of a foam when the surface is rubbed.

Frothing A foaming technique in which air or other gases that are mechanically whipped into the polyurethane mixture using a high-shear mixer prior to the foam reaction.

Gel Time The time between the discharge of the foam ingredients from the mixing head and the point at which the foam has developed enough gel strength to resist light impressions and is dimensionally stable.

Graft or Polymer Polyol Polymers with active hydroxyl groups that have other organic groups or polymers "grafted" to the polyol molecule. These grafted organic compounds serve to reinforce the strength or modify other properties of the flexible polyurethane foam product.

Hand Is the feel of the foam as the hand is rubbed lightly over the surface. For most furniture, bedding and textile applications, foam having a stiff or hard feel to the touch is described as having poor hand. In home furnishings, foam with a good hand has a springy, velvet feel, while abrasive pads, firm filler, and some packaging require a hand that is quite the opposite.

High Resilience (HR) Foam A variety of polyurethane foam produced using a blend of polymer or graft polyols. High resilience foam has a less uniform (more random) cell structure different from conventional products. The different cell structure helps add support, comfort, and resilience or bounce. High resilience foams have a high support factor and greater surface resilience than conventional foams and are defined in ASTM D3770.

Hot Molding A flexible molded foam production process in which high oven temperatures are used to drive the curing reaction in foams made from relatively low-reactivity polyols.

Hot Wire Cutting A high-temperature wire used to cut foam. This fabrication process is used typically for intricate parts. A ventilation hood should be used with this technique to exhaust fumes. Note: This procedure is not suitable for all foams.

Humid Aging An accelerated aging test method under conditions of high humidity and temperature. (ASTM D3547)

Hydrophilic An affinity for water.

Hydrophobic A repellency for water.

Hysteresis The ability of foam to maintain original support characteristics after flexing. Hysteresis is the percent of 25% IFD loss measured as a compression tester returns to the normal (25% IFD) position after measuring 65% compression. Lower hysteresis values, or less IFD loss are desirable. Current research indicates that hysteresis values may provide a good indication of overall flexible foam durability. Low hysteresis in conventional foam is equal to less IFD loss.

Indentation Force Deflection (IFD) A measure of the load bearing capacity of flexible polyurethane foam. IFD is generally measured as the force (in pounds) required to compress a 50 square inch circular indenter foot into a 4 inch thick sample, typically 15 inches square or larger, to a stated percentage of the sample's initial height. Common IFD values are generated at 25 and 65 percent of initial height. (Reference Test Method ASTM D3574). Note: Previously called "ILD (Indentation Load Deflection)".

Integral Skin Foam A molded foam having a dense, tough outer skin and a relatively lower density core. The product is achieved in a single pour using a combination of chemical and mechanical aids.

Isocyanate A shorthand name for the family of diisocyanates which are one of the two major ingredients in the chemical process by which polyurethane foam is made.

Laminating The bonding of layers of foam and/or other materials together into a single composite. This may be accomplished through adhesives or through heat processes like flame lamination.

Latex A natural rubber product which is not related to polyurethane foam.

Loop Slitter A mechanical slitter which allows continuous slitting of long buns of foam.

Mixing Head The device that mixes two or more component streams before dispensing the foam-producing mixture to the foam production surface or mold.

Mold Packing The practice of purposely adding more material to the mold than is actually required to just fill it. The extra material serves to accommodate slight changes in material temperatures, mold temperatures, and pour patterns. It is also a way to improve load-bearing properties without changing the foam formulation.

Molded Foam A cellular foam product having the shape of the mold cavity in which it was produced.

Open Cell Structure A permeable structure in flexible foam in which there is no barrier between cells, and gases or liquids can pass through the foam. Most cell walls have been ruptured to varying extent.

Peeling The process whereby thin sheets of foam are cut from a cylinder of foam. Similar to plywood peeling.

Pieced Flexible polyurethane foam that has been glued together from two or more smaller pieces. Commonly seen in cushioning to create special shapes or properties, or to use up small pieces produced during fabrication.

Pockets The undesirable formation of large cavities or pockets in the foam structure. Pocketing is usually caused by rapid formation and/or release of the blowing agent before the polymer structure has gained sufficient strength to contain the gas. [Also see "Splits".]

Polyester A polymeric polyol containing ester groups in the main molecular chain or in side chains.

Polyether A polymeric polyol containing ether linkages (carbon-oxygen-carbon links) in the main molecular chain or in side chains.

Polymer An organic substance composed of repeating chemical units built up into large molecules.

Polymer Density The density of the material made up strictly by the foam chemistry without fillers or reinforcements included.

Polyol A key chemical in foam formulation which, when mixed with diiso-cyanates and other specific ingredients, produces the reaction that causes flexible polyurethane foam to form.

Polyurethane Generally, a polymer connected by urethane groups. Urethane linkage and its supplements result from the reaction of polyol with isocyanate.

Pore Size The number of cells per linear inch.

Preflex The practice of compressing a flexible polyurethane foam sample up to six times to a predetermined thickness before determining IFD. (Reference ASTM D3574). Also used for other properties (e.g. resilience for HR foams).

Prepolymer A reacted, but not completely polymerized product. In the polyurethane industry, this is usually a prereacted product formed by reacting polyol(s) or water with diisocyanate(s). The materials normally contain residual free isocyanate groups for further reaction with more polyol(s) or water to produce the final polymer.

Pressure Release Collapse Shallow surface voids and/or shear collapse on molded foam parts caused by the sudden release of internal mold pressure or failure of the mold to seal. Usually seen with shiny surfaces and a thin surface skin similar to cold collapse.

Primary Backing (carpet) The material through which the carpet fibers are tufted.

Prime Carpet Cushion Polyurethane carpet cushion which is made from slabstock polyurethane foam.

Protocol For Residential Walk-On Test A standardized testing procedure that can be used by carpet manufacturers, cushion producers, distributors and retailers to evaluate installed residential carpet system performance.

Rebonded Foam That foam resulting from a process of adhering small particles of foam back together again to make a usable cushioning product. Various adhesives and bonding processes are used. A typical application for rebonded foam is as carpet underlay. [Also see Bonded Foam.]

Recovery The return to original dimension and properties of a flexible polyurethane foam sample after a deforming force is removed. Reinforced Foam [See "Filled Foam".]

Resilience An indicator of the surface elasticity or "springiness" of foam. It is measured by dropping a steel ball onto the foam cushion and measuring how high the ball rebounds.

Reticulated Foam Flexible polyurethane foams characterized by a three-dimensional skeletal structure with few or no membranes between strands. Reticulated foams are generally used as filters, acoustical panels, and for controlled liquid delivery.

Roll Goods Flexible polyurethane foam that has been peeled from a foam "log" or slit from a bun and rolled onto a core for handling purposes. Rolled foam sheets are commonly used for large area padding, such as carpet padding and as quilting foam in mattresses.

Scorch A yellow or brown discoloration of the foam, particularly in the core. Scorching is caused by excessive heat during the exothermic reaction. It occurs mainly in high-water flexible slabstock formulations.

Seam The splice line formed by two or more separate pieces of flexible polyurethane foam that have been bonded together.

Shiners Light reflected from intact cell walls, noticeable on the cut surfaces of flexible polyurethane foam. A large number of shiners, or shiny spots, indicates a foam with many closed cells.

Shredded Foam Flexible polyurethane foam that has been mechanically torn into small pieces or crumbs, for the purpose of creating a loose filling material.

Skin The higher-density outer surface of a foam usually occurring when the foam surface cools more rapidly than the core.

Slab A section of foam cut from the interior of a large bun.

Slab Stock Flexible polyurethane foam made by the continuous pouring of mixed liquids onto a conveyor, creating a continuous loaf of foam.

Slabstock Production Process One of the two basic procedures used to manufacture foam. A continuous process in which the reacting foam chemical mix is dispensed on to a moving conveyor belt where the foaming process is completed. This foam is subsequently fabricated into useful shapes.

Slitting The process where sheets of foam are cut from a rectangular foam block.

Static Fatigue The loss in load bearing properties of a flexible polyurethane foam sample under constant compression of 75% for 17 hours at room temperature. (See "Test Method ASTM D3574"). **Struts** The structural members of a foam material. These roughly triangular features contain most of the solid polymer and form the cell shape.

"Supersoft" Foam Foams that have an IFD measurement within the 4 to 10 pound range having a comparable feel to fiber.

Support Factor (see Compression Modulus) Support Factor = $\frac{65\%IFD}{25\%IFD}$ determined after one minute of rest or recovery. When the support factor is known it can be used in conjunction with a known 25% IFD value to determine the 65% IFD value. Seating foams with low support factor are more likely to bottom out under load.

Surface Firmness The number of pounds of force necessary to indent a foam sample by 25% of its original height.

Surfactants A term to describe substances that provide resiliency and stability to thin films and that markedly lower the surface tension of liquids, thus permitting easier bubble formation. An integral part of the foam manufacturing chemistry.

TDI An abbreviation for toluene diisocyanate.

Tear Strength A measure of the force required to continue a tear in a foam after a split or break has been started and expressed in pounds per inch (lbs/in.). This property is important in determining suitability of foam in applications where the material is sewed, stapled, or otherwise anchored to a solid substrate. Also important in demoldability. (ASTM D3574).

Tensile Strength The pounds per square inch of force required to stretch a material to the breaking point. (Reference ASTM D3574).

Tight Foam Flexible polyurethane foam with many closed cells, resulting in low air flow measurements.

Total Vertical Motion (TVM) The deflection of a seating system during sitting.

Urethane Actually a misnomer as applied to polyurethane foam. A colorless, crystalline substance used primarily in medicines, pesticides, and fungicides. Urethane is not used in the production of urethane polymers or foams. The urethanes of the plastics industry are so named because the repeating units of their structures resemble the chemical urethane.

Virgin Foam Unfilled flexible slabstock foam that has not been processed in any manner other than cutting to shape.

Voids The undesirable formation of large cavities or pockets in a foam structure. Voids are usually caused by poor moldability or incorrect mold filling. In the case of foam buns, voids occur when the blowing and polymerization reactions are out of balance.

Water Blown Foam Flexible polyurethane foam in which the gas for expansion is carbon dioxide generated by the reaction between water and an isocyanate material. All flexible polyurethane foam is water blown, although auxiliary blowing agents are often used to obtain special physical properties.

Windows The thin membranes formed between cell struts. Windows may be present (a closed-cell foam) or absent (an open-cell foam) depending on the particular foam chemistry used.

