Chapter 2

Manufacturing of ESCS Lightweight Aggregate

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CHAPTER 2

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Chapter 2 Manufacturing of ESCS Lightweight Aggregate

2.0 Introduction and Overview

This chapter describes the manufacturing of expanded shales, clays, and slates (Fig. 2.1) and is intended for sales, marketing, field service and administrative personnel. Far too simplistic for those directly involved with the actual production process, it is only intended as a brief overview, allowing a measure of completeness to this handbook. A large part of the information covered in this chapter was directly derived from the publication authored by Harry Wilson "*Lightweight Aggregates for Structural Concrete",* Materials Research Program, CANMET Report 76-12, (1976).

Although the first systematic investigation into the production of ESCS lightweight aggregates was undertaken in 1908, it was not until ten years later that the product found commercial application. The process of manufacturing an ESCS aggregate in a rotary kiln was patented by Stephen J. Hayde, a Kansas City ceramic engineer who recognized that clay brick that had excessive expansion could in fact, be utilized in the production of high quality lightweight aggregate for use in concrete products that had a significantly improved strength to weight ratio.

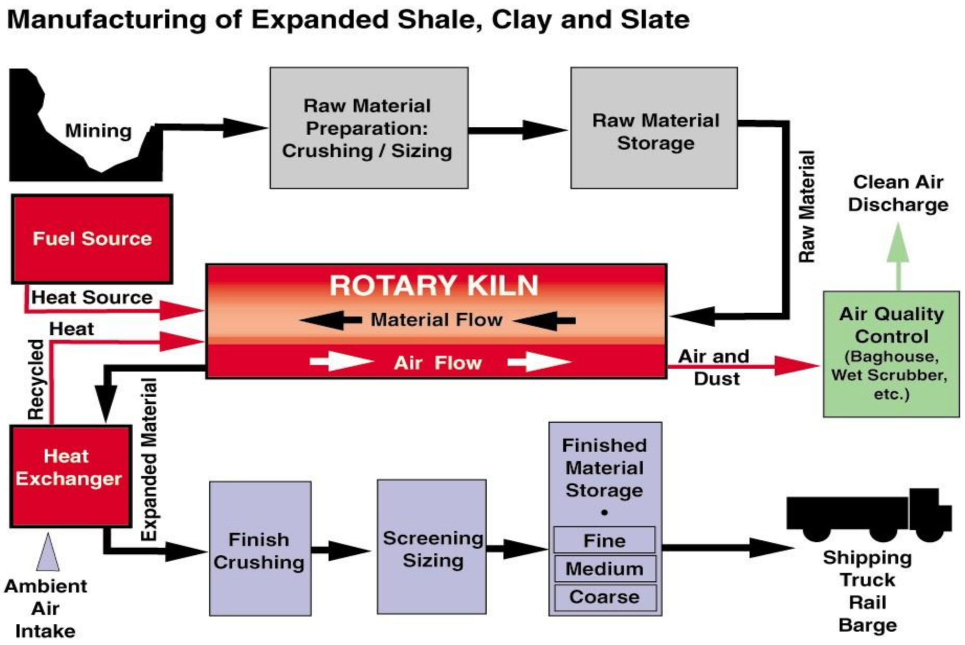

Figure 2.1 ***Flow Diagram of the Manufacturing Of Expanded Shale, Clay and Slate***

2.1 Geology

The most widespread materials that are used to produce lightweight aggregates are the surface clays, shales, and slates. These materials have been derived from the decomposition of pre-existing rocks by weathering. This transformation is promoted by the natural forces of wind and water causing decomposition of the various components of the rock. The components of the rock react in various ways to the action of these natural agents of degradation; the major constituent of granite is not readily altered, but feldspars change to carbonates, clay minerals and silica.

Decomposition can extend to a significant depth below the surface, but is primarily limited to the depth of the water table because of the lack of oxygen and carbon dioxide below this depth. Decomposition may be accompanied by disintegration, the mechanical fracturing of rock masses, resulting from frost action, changes in temperature, wedging by plant roots, growth of minerals, and abrasion. Decomposition products may remain in place or be moved by air, water, ice or a combination of these agents. Transportation may be for only a short distance or for many miles to a completely different environment, and the resulting deposits may be shallow or of great depth.

Clays are generally of extremely fine grains of material with most particles less than .005 mm in size. The majority of these grains are clay minerals. Some authors differentiate silt from a clay in that more than 50 percent of the grains of silt are between 0.05 and 0.005 mm. Claystones and siltstones are indurate clays and silts. When pressed into bedding, they are classed as shales. Weakly metamorphosed claystones are referred to as argillites. Slates are any predominantly argillaceous, rock in which slaty cleavage has been developed by metamorphism.

The argillaceous materials differ widely in composition, consisting of a variety of minerals. Silica is the predominant chemical component. It is present as part of the clay minerals and undecomposed silicates, and as free silica, usually quartz. Alumina is present in the clay minerals and other silicates such as feldspar. Iron occurs as oxides, in chlorites and micas and other iron silicates, and as pyrite, marcasite and siderite. Lime and magnesia are present in carbonates, silicates, or in gypsum. The alkalis occur in feldspars or in clay minerals. Minor constituents include titania, manganese, phosphorus and organic matter.

Clays and shales, and slates are generally used in the manufacture of lightweight aggregates. To be suitable, it must bloat when heated to incipient fusion (Fig. 2.2).

2.2 Mechanism of Expansion of Clay and Shale

A clay, shale or slate which will bloat or expand must possess two qualities:

a) When it is heated to the point of incipient fusion, gases must be formed;
b) The glass formed on heating the material must be of such a viscosity as to entrap the gases formed.

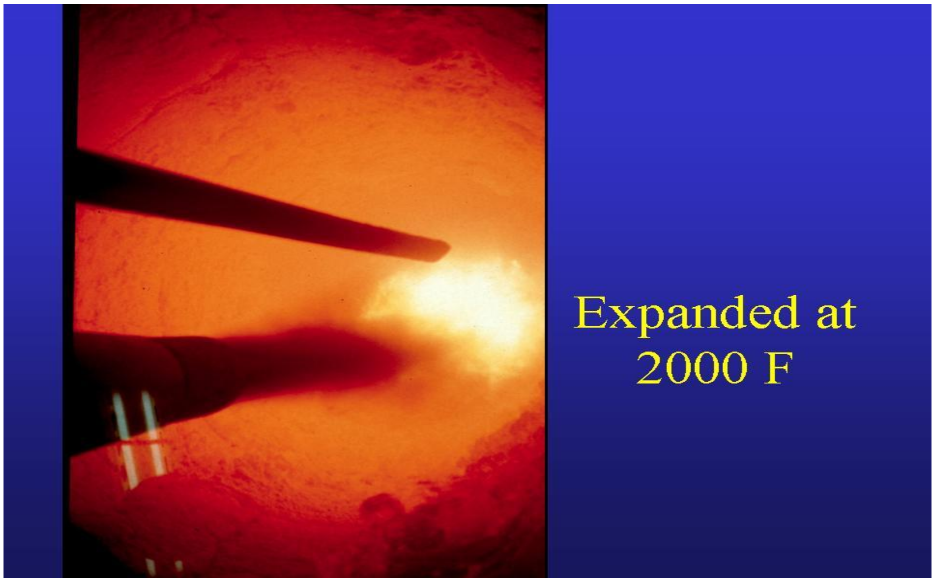

Figure 2.2. ***During its transit through the rotating kiln, the raw material expands in the bloating zone near the end of the kiln.***

This bloating phenomenon has been of interest for many years. To the manufacturers of brick it is an undesirable property and must be avoided. Bricks are heated at a rate such that the gases will be evolved before the glass begins to form. Many researchers have advanced theories on the phenomenon of bloating. The most comprehensive early report was published in 1948 by Conley et. al. This was followed by Hamlin in 1962.

Riley plotted the chemical compositions of a large number of clays on a triaxial diagram (Fig. 2.3) and found a limited area within which bloating clays fell. He considered that this area bounded the composition limits from which a sufficiently viscous glass would be formed on heating. Some non-bloating clays within these limits did not contain gas-producing compounds, although the optimum glassy phase was formed. He adjusted the compositions of some non-bloating clays which fell outside the “bloating area” to bring them within the limits, by additions of silica and alumina, and found they bloated. He also produced artificial clays from kaolinite, silicic acid and microcline feldspar so that their compositions fell just outside the limits. He adjusted the compositions with additions of various gas-producing compounds (pyrite, hematite, calcite, dolomite, siderite, magnesite, pyrite plus calcite, and hematite plus calcite) and brought the compositions within the bloating limits. Only 14 of 52 compositions bloated well, the remainder bloated poorly or not at all. The gas-producing compounds that were added also acted as fluxes; it is evident that the combination of fluxes is important because not all are of equal activity.

Many researchers have studied surface tension and viscosity and showed that; silica and alumina increase the viscosity of the glass. Soda and potash widen the vitrification range (temperature range between the start of vitrification and fusion), and calcium, magnesium and ferrous oxide decrease the viscosity and shorten the vitrification range.

The basic crystal structure of most clay minerals is made up to two components, a tetrahedral layer of (Si, Al) – 0 and an octahedral of (Al, Mg, Fe) – (0, 0H). The fundamental structural unit of the kaolins is composed of one tetrahedral and one octahedral layer. The micas, illite, montmorillonite, and vermiculite consist of single octahedral layers sandwiched between two oppositely-facing tetrahedral layers. The sheet thus formed is separated by cations which may be readily exchangeable (montmorillonite) or non-exchangeable (mica). In chlorites, these interlayer cations are replaced by an octahedral-coordinated layer having the composition (Mg, Fe, Al) $(OH)_2$.

The alumina-rich kaolin minerals do not bloat because a glassy phase is not formed until they are heated to 2550ºF (1400ºC). Illites, montmorillonites and chlorites bloat because their high content of alkali or alkaline earth elements promotes the formation of a glassy phase at 1740º to 1920º F (950º to 1050ºC). These minerals also retain a percentage of water up to the temperatures at which bloating normally occurs.

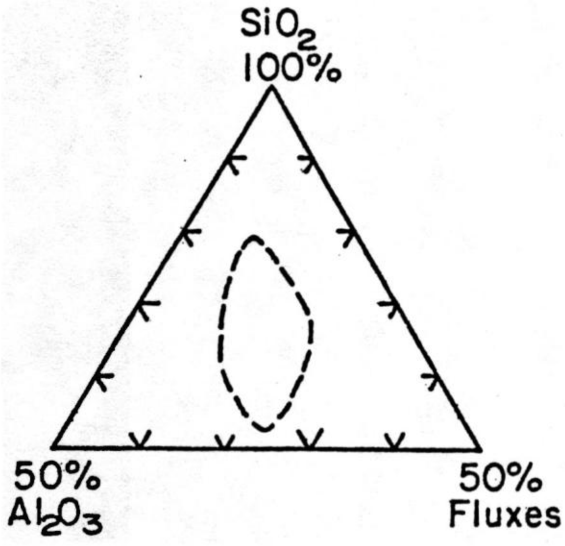

Figure 2.3 ***Composition limits of bloating clays***

Most authors agree that it is not sufficient to say that the composition shown on a triaxial diagram, as in Fig. 2.3, will determine the viscosity of a glass. It depends on the clay minerals and on the combinations and ratios of the fluxes. A comprehensive listing of references to the bloating and vitrification of fired clays was reported by Wilson H.S., 1979.

As reported by researchers, in over 50 percent of the bloated clays, carbon dioxide was the sole bloating gas. Others contained carbon dioxide and Sulphur dioxide, but never Sulphur dioxide alone. They found that calcite was the predominant source of carbon dioxide, with dolomite and ankerite less common sources. In a few cases, coal was the only source of the gas. Pyrite and, in some cases, marcasite were the sources of the Sulphur dioxide.

Wilson improved the bloating of poor-bloating clay through additions of lignosulphonates (calcium-ammonium, calcium, and sodium), flour, and sodium carbonates. Additions of 2 percent were adequate with all additives.

Other investigations found that both organic matter and calcium carbonates produced carbon dioxide, which caused bloating. Either by removing the organic matter or by destroying the calcium carbonate, the bloating of the silt was reduced; when both operations were performed, the silt did not bloat.

From the foregoing discussions it is evident that there is a diversity of opinion on the actual causes of bloating. From the works of these authors it is evident that the chemical composition of a clay determines the viscosity of the glass formed on heating. If the fluxes are present in sufficient quantity and the alkaline earth content is relatively low, the viscosity of the glass formed will be adequate to entrap the bloating gases. Also, the clay minerals should be montmorillonite, illite or chlorite. Others not reported here shows that the bloating gases may be one, or a combination, of carbon dioxide, sulphur dioxide, oxygen and water. These gases can be formed from carbonates, organic matter, sulphates, sulphides, clay minerals and ferric oxide.

2.3 Mining/Quarrying

The method used in quarrying depends on the nature of the deposit and the size of the operation. The topography of the area is important in planning the quarry operation; a land surface which is flat can result in problems that are not present in a sloping land surface. In areas where rainfall is appreciable, drainage can be a problem. Water which collects in a quarry usually has to be pumped out. The quarry could be worked in such a way that water would drain to a lower unused section while the higher, drained section was being worked.

Invariably, the material to be processed is overlain by undesirable material that will have to be removed. In sloping land surfaces, this can be less of a problem than in flat-lying land. If the surface drops away sharply at the edge of a deposit, such as at the side of a valley, the overburden frequently can be pushed over the edge of the embankment. In flat country, the overburden must be collected and transported a sufficient distance so that it will not have to be moved a second time to uncover the desired material. The amount of overburden that can be removed economically depends on such factors as the topography and geography of the deposit and the distances the overburden and raw material have to be transported. The dip of the deposit, the angle at which the bed is inclined from the horizontal, should be considered. Clays are usually horizontal, shale beds frequently dip at appreciable angles and the dip in slates can be considerable. It may be uneconomic to strip overburden from a deposit of shale over the desired area if the dip is appreciable. The overburden may be slight in one area, but excessive a short distance away.

Figure 2.4. ***ESCS is produced from deposits of*** *shale's*, ***clays, and slates. These minerals are principally composed of silica and alumina, similar to those used in brick and other ceramics known to be extremely durable. From the quarry (deposit) the raw material is taken to the preliminary crushing/screening plant, and then expanded in a rotary kiln.***

Clay, being relatively soft, can be recovered for processing by some type of a tractor-drawn scraper, a tractor with a front-end loader attachment, a power shovel, a drag line, or a back-hoe. All of these machines are available in various capacities to suit the size of the operation. A scraper or front-end loader would be better suited to relatively shallow deposits; whereas the shovel, drag line or back-hoe would be of more use in deeper deposits. The clay may not be uniform, but may vary in composition and properties at different levels. Frequently a clay deposit will weather at the surface with consequent leaching out of some components because of the action of rain; the depth of weathering depending on exposure to water and air. Deposits may vary at different levels, having been deposited at different times and under different conditions. It might be desirable to blend the various clays in a deposit, in which case a shovel, drag line, back-hoe or clay planer would be the most appropriate type of recovery equipment. It may be desirable to use only certain levels in the deposit, in which case the undesirable material would have to be removed.

Shales are of various hardnesses. Some can be dug from the deposit by the machines mentioned, without prior treatment, whereas if too hard to be dug, a tractor with a ripper attachment might be adequate to break them up. The depth loosened, depends on the hardness of the shale. Harder shales and slates would have to be drilled and blasted to break them up.

The material can be moved from the quarry to the plant by various means; the truck being the most maneuverable and versatile means of transport. The belt conveyor is usually a relatively fixed apparatus and must be fed by some other equipment. Nevertheless, it can be extended or moved periodically as the point of loading has to be moved.

Generally, quarrying is done during an 8-hour period, whereas the plant operates for the full 24 hours. Particularly if the raw material is clay, inclement weather, such as rain or snow, could make it impractical to quarry, and storage space should be provided to maintain raw material feed to the plant.

2.4 Preparation of Raw Material

Preparation primarily involves crushing and sizing. The crushing can be done by jaw, rolls, gyratory or cone crushers, or by hammer or impact mills. The type of crusher used depends on the crushing characteristics of the material and the size desired, the optimum shape of the crushed particle being a cube. The shape is important because it governs the shape of the resulting aggregate. Crushing might be done in a single operation or it might include secondary crushing combined with screening before the desired sizing is achieved. Vibratory screens are usually employed.

The jaw crusher is the most popular primary crusher for shales, slates and relatively dry clays. Wet or sticky clays would tend to plug this type of crusher.

There are several types of roll crushers. Single roll crushers usually have knobs or teeth around the periphery of the roll, which abrade and spall the material against a concave breaker plate. This is not a common type of crusher. It is useful on semi-hard or slightly wet material. Double-roll crushers are either smooth, corrugated, or toothed. They are effective on semi-hard and wet material. If the clay is sticky it is advantageous for one roll to rotate more rapidly than the other. The rolls rotating at unequal speeds tend to shred the clay.
There are many slight variations of gyratory crushers, differing in the slope of the cone. The cone crusher is generally used as a secondary crusher on hard material.

In a typical hammer mill the rotor, equipped with hammers, revolves at high speed. The material is crushed by both the impact of the hammers and by being thrown against the breaker plates. When the material has been crushed sufficiently, it passes between the screen bars at the bottom of the machine. It can be used on a variety of materials.

An impact mill differs from a hammer mill in that the rotor revolves at higher speed and the machine does not contain screen bars.

Depending on the firing characteristics of the material and the type of product desired, the material might have to be screened into fairly closely sized fractions. The kiln feed should be sized so that the product from the kiln requires a minimum of crushing to produce the desired sizes of aggregate.

With shale or slate as the raw material, the crushing and screening (Fig. 2.5) operations are usually all that are required to prepare the feed for the kiln. This also applies to some clays. Other clays however, are too soft or friable to withstand handling, and they crumble, resulting in too many “fines”, while others are not sufficiently dense to entrap the bloating gases, resulting in a poor product. It may be necessary to blend two or more clays and, in cases such as these, the clay maybe pelletized or extruded.

Figure 2.5. ***Double Deck, Vibratory Screen***

Figure 2.6. ***Pan Pelletizer***

Pelletizing

The palletizing disc or pan is an inclined disc (about 45 degrees) revolving about its central axis and having a rim extending above the surface of the disc. The rim may be perpendicular to the disc, may slope outward or may rise in steps. The action as the disc revolves is an alternate wetting of the particles with a water spray and a coating of dry material. This action causes a snow-balling effect as the particles gradually increase in size.

The largest spheres move to the periphery of the disc and discharge over the rim when they have reached the desired size. The size depends on the slope and rotational speed of the disc, the height of the rim, and the points of introduction of dry material and the water.

Extrusion

The extrusion machine is a horizontal tub in which a shaft incorporating a series of knives or blades along its length mixes clay or shale and water until the clay reaches the plastic state. The knives are set at an angle so that, as well as mixing, they move the material along the tub. An enclosed auger on the end of the shaft picks up the plastic clay and extrudes it through a die. The tub may contain two shafts with knives. These shafts, which rotate in opposite directions, are used when the clay has low plasticity and they should give better mixing and pugging than the single shaft. The machine may also incorporate a vacuum chamber. The plastic clay drops from the end of the tub into a chamber from which air is extracted by a vacuum pump. An auger in the lower portion of the chamber extrudes the deaired clay through the die. Deairing the clay makes it denser and usually results in a better bloated material.

The die may be either a perforated plate or a heavy-wire screen. The streams of clay issuing from the die are cut off by a revolving knife or break off under their own weight. The extruded pellets are denser than those made by the other machines and in most cases result in greater bloating.

Provision should be made for the storage of prepared raw material. Usually enough is prepared in one shift to keep the plant operating for three shifts. Prepared material should be on hand in case the crushers or pelletizer require minor repairs. Thus, storage for at least one day’s production should be provided.

The prepared feed passes through a surge bin and into the rotary kiln. The surge bin permits feed to the kiln at a constant rate, which is very important to a successful kiln operation. The lumps of clay are broken down and are pelletized as they travel through the kiln.

Figure 2.7. ***Extrusion Machine***

The sizing of the feed is very important to the quality of product; the larger lumps or pellets require more heat than do the smaller pieces to give equivalent bloating. Depending on the particular raw material, the feed needs to be sized closely for maximum efficiency.

2.5 Firing in a Rotary Kiln

The rotary kiln, in its simplest form, is a nearly horizontal refractory-line cylinder, rotating about its longitudinal axis. The raw material is fed into the upper end and the heat is applied at the lower end, the material traveling counter-current to the heat flow. The material is heated in about 30 to 60 minutes, depending on the length, diameter, and rotational speed, to a maximum temperature of between 1920º and 2190º F (1050º and 1200º C). The heating rate is gradual for about 2/3 the length of the kiln, then it increases rapidly until the maximum is reached thus heating the interior of the particles so that gases will be liberated to be trapped by glass formed matrix.

Sources of basic information on rotary kiln production include, "*The Rotary Cement Kiln",* Peray 1986 and "*Production of Keramzit",* (Rotary Kiln Expanded Clay, Shale and Slate, Onatski O.L., 1971 (In Russian). The kilns used in existing plants are of various lengths, from 60 to 225 ft (18.3 to 68.6 m), and diameters, from 6 to 12 ft (1.8 to 3.7 m). Most kilns are of one diameter throughout the entire length, (Fig. 2.8), but some are of two diameters, the larger diameter being at the bloating zone. The material moves more rapidly in the smaller preheat zone than in the larger bloating zone.

Figure 2.8. ***View of a Rotary Kiln Plant***

Rotary Kiln Efficiency

The rotary kiln is an inefficient heat exchanger. In some plants only a small percentage of the heat applied is actually used to bloat the material. The remainder of the heat is lost through:

(a) The combustion gases and moisture exhausting from the kiln;
(b) Radiation from the kiln shell;
(c) Retention in the aggregate discharged from the kiln.

With increases in the cost of fuel, the efficiency of the bloating operation is of great importance to the producer. Various means of reducing the heat losses are possible. Longer kilns reduce the temperature of the exhaust gases, more of the heat being absorbed by the material; the radiating surface at the kiln is increased however. Smaller diameters reduce both the unoccupied kiln volume and the radiating surface of the kiln. Product coolers recover some of the heat contained in the aggregate discharged from the kiln, the heated air from the cooler being re-introduced into the kiln usually as secondary combustion air. Rotary coolers are typically in the range of 4 to 10 ft (1.2 to 3.1 m) in diameter; they are usually refractory lined for at least half the length. Traveling grate coolers are more flexible than rotary coolers in that the quantity of air flowing from the grate cooler into the kiln can be regulated, whereas all the air from the rotary cooler goes into the kiln. The grate cooler is a more efficient heat exchanger than the rotary cooler.

Another, approach to the problem of heat loss is to recover heat from the exhaust gases by using a raw material preheater. This can be a single or multiple chamber arrangement in which the material is in more intimate contact with the flue gases than in the kiln and better heat transfer is attained. It is installed immediately preceding the kiln. One source showed, by the use of a heat balance, that 36 percent of the heat being consumed in a particular lightweight aggregate operation could be saved through the use of a preheater. Wilson used a laboratory model rotary kiln to show that the material used in this operation could be preheated to 930^{o} F (500^{o} C) without decreasing or increasing the bloating presently being achieved in the rotary kiln.

A further approach to this problem of heat wasted with the exhaust gases involves kiln internals such as lifters, dams, or quadrants. The principle of internals in the feed end of the kiln is similar to that of a preheater: the material is in more intimate contact with the hot gases and better heat transfer is accomplished. Biege and Cohen (20) found that internals produced a fuel saving of approximately 564,000 Btu/ton (650,000 j/kg) of product, or 21 percent.

The adjustment of the burner or burners in a rotary-kiln installation will affect the efficiency of the process as well as the quality of the product. The fuel: air ratio in the burner will affect the atmosphere in the kiln, and could have a marked effect on the glass-forming temperature of the raw material which is lower in a reducing atmosphere (the fuel is not completely burned). This could result in improved bloating over that achieved under oxidizing conditions (complete combustion). The direction and shape of the flame within the kiln will affect the heat transfer from the flame to the bed of material. A long thin flame will transfer its heat over a greater length of the kiln than will a shorter, broader flame. A very short flame that liberates all its heat in the first few feet of the kiln will result in a high surface heat in the material, whereas the interior of the particles would obtain insufficient heat to provide for proper expansion. Most commercial burners have built-in adjustability and a variety of conditions can be used until the best has been obtained. The bloating-temperature range of a clay, shale or slate is the range between that temperature at which minimum acceptable bloating occurs and that at which sticking of the particles is excessive. It could be as little as 30 Celsius deg (50 Fahrenheit deg), and as a result extremely accurate temperature control is required. The bed of material has to be uniformly heated to produce a uniform lightweight aggregate.

Pulverized coal, fuel oil, natural gas and waste fuels have all been used to supply heat, and the economies of the various fuels available should be considered.

The use of an aggregate cooler from which heat is recovered and introduced into the kiln as the combustion air increases the temperature of the flame and also reduces the total heat input required. The efficiency of the rotary cooler can be increased by the use of either internal or external insulation, or by erecting a stationary shield around the hot end.

In a rotary kiln plant, control of the draft through the kiln is important. Fluctuation in draft will result in fluctuation in temperature, and consequently variation in the quality of the product. The most positive way of controlling draft is to make use of a fan in the exhaust system, equipped with a mechanically or electronically-controlled damper. The controls on the damper sense changes in draft due to changes in conditions in the kiln and compensate to continuously regulate the draft.

To meet environmental requirements, it is essential that the dust from the stack be controlled. A cyclone or series of cyclones is effective in collecting the coarse particles in the dust, while electrostatic precipitators, wet scrubbers and glass bag collectors are most efficient in removing the fine dust from the gases. The electrostatic precipitator cannot be used effectively in all applications because many clays, shales and slates exhibit resistivity to an electrostatic charge. The wet scrubber necessitates a supply of water and an area for a settling pond. The glass-bag collector is the most efficient dust collector. The efficiency of the electrostatic collector is partly dependent on the moisture content of the gases, and the efficiency of the scrubber depends on the velocity of the gases. The temperature of the gases is critical in the bag collector; above 600º F (315º C) the bags may be burned, and below 350º F (175º C) condensation of moisture may be a problem.

Figure 2.9 is an aerial view of a Lightweight aggregate plant.

2.6 Finish Grading Of Aggregates

Aggregate producer stock lightweight aggregate materials in several standard sizes that include coarse (normally 3/4" to #4 or 1/2" to #4), medium (3/8" to #8 or #16) and fines (#4 to pan) grading.

Figure 2.9. ***Aerial View of Plant***

A variety of crushing equipment can be used to make the final grading, such as jaw, rolls, cone, gyratory or impact crushers. The choice of crusher could affect the shape of the crushed aggregate as well as the grading. The optimum shape is a cube. The crusher should be selected so that a single crushing operation would give the desired grading, if possible. Crushing should be done in circuit with screens so that over-sized particles can be returned to the crusher.

Storage of the sized lightweight aggregate is important. The finer the size of the aggregate, the higher is the relative density, and this difference in relative density could result in segregation in storage.

As an example, aggregates for structural lightweight concrete usually have a top size of minus 3/4 in. or minus 1/2 in. Most structural lightweight concrete applications are a blend of LWA and natural aggregate or sand. Typically the coarse aggregate, 3/4 in. to 4 mesh (1/2 - #8) is lightweight and the fine aggregate, minus 4 mesh (minus 4.8 mm) is ordinary sand, however other combinations of LWA and natural aggregate are used.

Aggregate for lightweight concrete masonry units are normally sized minus 3/8 in. (9.5 mm). This aggregate is usually the crushed variety because of improved machining characteristics and the zero slump concrete mixture is drier than that for fresh structural concrete.