Chapter 3

Principles of Design

Six critical factors must be considered before you begin to design a kiln. This chapter reviews those considerations, then discusses the nine principles of good kiln design. These basic principles are then incorporated into the four distinct types of kilns discussed in succeeding chapters on crossdraft, downdraft, updraft configurations and multi-directional draft configurations.

PRELIMINARY CONSIDERATIONS

**Kind of kiln:** Will you build an updraft, downdraft, crossdraft, circular dome, or salt glaze kiln? Will the kiln be 10, 20, 25, 45, or 150 cubic feet or larger? You must carefully calculate your requirements before you begin the design.

**Clay to be fired:** The type of clay you plan to fire will determine the type of kiln you need, its size, the fuel to be used, and so forth. Kilns may be planned and built specifically to fire terra cotta clay, sewer pipe clay, earthenware, stoneware, porcelain, or any of a number of possibilities. In fact, the potter should know the clay and ware so well that he can design the kiln to enhance the pottery and to control the effects of firing.

**Atmospheric conditions:** The chamber shape will depend on whether the kiln is intended for oxidation, reduction, or perhaps middle fire. Burners and dampers can greatly affect the ability of the kiln to oxidize or reduce. This, in turn, affects clay bodies and glazes and their outcome.

**Available fuel:** It would be foolish to build a wood-burning kiln in the city; it's a romantic idea but impractical. Therefore, the relative availability of natural gas, propane/butane, oil, wood, coal/coke, and electricity must be considered. Since propane/butane and electricity are available almost anywhere, and are clean burning, they can be used anywhere except where natural gas is provided. Natural gas is a perfect fuel for use in cities or highly populated neighborhoods; however, before one proceeds, ascertain the amount of gas available to the site. Wood, coal/coke, and oil should be reserved for use in the country.

**Location of kiln:** Whether city, suburb, backyard, garage, manufacturing area, or countryside, all locales tend to "self design" a kiln. By this I mean that each location tends to dictate what kind of kiln is feasible, a wood kiln in a garage is not the best idea, nor is an anagama in the suburb. Many areas will have building code restrictions that affect what kind of kiln you can use. Be sure to check local regulations before spending any money.

**Shelf size:** Be sure your kiln is designed to accommodate one of the standard shelf sizes.

DESIGN PRINCIPLES

Once the basic requirements are determined, as outlined in the preceding section, the nine principles covered here become an integral part of every kiln design.

PRINCIPLE 1

**A cube is the best all-purpose shape for a kiln.** The best design for an updraft kiln has the arch on top of the cube, not contained within (Fig. 3-1). This allows for the best stacking space. Also, the volume of the arch serves as a collection area for the flue gases. Increasing the height of the cube chamber with a fixed width decreases the efficiency of even-temperature firing (Fig. 3-2). I do not know what the ratio factor is between increasing height and uneven temperature. From experience in firing an updraft kiln (2' x 3' base x 5'-plus-high stacking space) with burners in the floor, I have found from 1/2 to 1 cone difference between top and bottom, no matter what firing schedule was used. However, on the same kiln 1 foot

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**Fig. 3-1:** A cube is the best all-purpose chamber shape.
shorter (2' x 3' x 4') it can be dead even top to bottom. In a similar kiln (3' x 3' x 5' stacking space), I found a constant 1/2 to 1 cone difference in the firing temperature between top and bottom but if the width and length was increased to 4 feet, the temperature evens out perfectly. My conclusion is that equal height and width is extremely important to even temperature when using floor level burners. From my experience, the same findings also apply to the downdraft and crossdraft kiln design. Increasing the length of the cube has no effect on the even firing efficiency of the kiln, hence the development of tunnel kilns (Fig. 3-3), and other long tube-type kilns used commercially. In circle or round-dome kilns, (Fig. 3-4), the diameter and height should be nearly equal, depending upon whether it is an updraft or a downdraft kiln. Most small downdraft kilns tend to include the dome in the height measurement, while updraft beehive types tend to add the dome to the height measurement. (See Appendix for estimating data on arch construction.) For firing tall kilns (Fig 3-2), the burner becomes important and should be placed up the sides of the kiln (See Chapter 9). There are other specialty kiln designs, not based on the cube, like the tube, groundhog and derivative kilns, but follow other principles listed here.

**Fig. 3—2:** Increasing the height of a cube chamber decreases firing efficiency.

**Fig. 3—3:** Increasing length does not affect firing efficiency.

**Fig. 3—4:** Diameter and height should be nearly equal in circular or round-dome kilns.

**Fig. 3—5:** Heat direction should follow the arch.

**PRINCIPLE 2**

The chamber shape is determined by heat direction and ease of flame movement to allow a natural flow. Two important rules to remember are: (1) the flame and heat direction should follow the arch (Fig. 3-5), and should not be at right angles to the arch (Fig. 3-6); and (2) the flame movement and heat direction should have only two right angles to negotiate within the chamber, usually located at the firebox inlet flue and bagwall and at the exit flues. Right angles can cause irregular heating or hot spots, which could lead to refractory failures and firing inefficiency. Fig. 3-6 also depicts the basic groundhog kiln design which is an effective kiln design (see Chapter 4). Nevertheless the fact remains it produces hot areas along the crown following the directional arrow, which leads to cool areas along the bottom back side wall and refractory failure at the back wall. If the design runs contrary to the arch then the transition should be curved or shaped from the firebox up into the volume and then into the chimney wall or chimney flue. This is possible with the use of lightweight insulation castables as done in the Gulgong racer, or with brick work as in the Ellington kiln. (See Gulgong racer and Ellington new kiln, Chapter 4). Kilns that run contrary to this principle are the Nils Lou Minnesota flat-top kiln design and some professionally made gas-fired pseudo-downdraft kilns. They show
PRINCIPLE 3

A specific amount of grate area or combustion area is needed for natural draft. Grate area (firebox or fuel combustion area) depends upon the fuel used, following these approximate guidelines to get started:

Wood: 10 times greater than the horizontal section of the chimney, or put another way, the grate combustion area to chimney cross section area at the base ratio is 10 to 1.

Coal: 1 square foot of grate to every 6 to 8 square feet of floor space.

Oil: 1 square foot of combustion area to every 5 square feet of floor area.

Gas: 4 1/2" minimum channel combustion space between ware and wall, usually the length of the wall.

This is the most difficult principle of kiln design to apply, but it is the real heart of the kiln, for it determines the draft rate. When in doubt, be generous. Better a grate area too large than one too small. It is also better to have a chimney area on the large side instead of too small.

When designing kilns the fireboxes or combustion area and chamber are usually designed first, then the chimney matched to the size of the grate area or combustion area and chamber. If your calculations come out short of brick sizes, then opt for increasing the area up to match the brick sizes. To give examples of the wood guideline, I will use the fastfire downdraft and a crossdraft design.

The fastfire kiln has two fireboxes under the floor equaling 810 square inches of grate area which is divided by 10 giving a chimney of 81 square inches or 9" x 9". If the fastfire grate area is 1,215 square inches dividing by 10 gives a chimney of 121.5 square inches or 9" x 13.5" (Fig. 3-8). A crossdraft with a firebox of 60" side by 36" deep gives a grate area of 2,160 square inches divided by 10 equals a chimney of 12" x 18" or to match brick sizes, would be built as 13.5" x 18" (Fig. 3-9). I have found that over the years I have tended to use a larger ratio of about 7 to 1 (firebox-to-chimney ratio) in wood kilns because it allows for a more forgiving firing technique, fires faster when needed, adjusts for altitude, and allows for more adjustability in altering flues, chimney height and dampering. The groundhog kiln uses approximately a 4-to-1 ratio (Fig. 3-10).

In natural-draft kilns the inlet flue areas must be equal to exit flue areas for the simple reason, "what comes in must go out." If exit flues are too restricted, this will slow down the flow and retard combustion efficiency, thereby affecting the temperature increase. The combined area of the inlets should be equal to the chimney section. If the latter is 162 square inches, then the inlet flue area should be about 162 square inches. Since the normal flue size is a brick size (9" x 4 1/2"), four flues of this size would equal 162 square inches, adequate for a chimney with a cross section of 162 square inches. At the point where the exit flues enter the chimney, they should be restricted so that
the chimney cross-section is larger than this flue area. This can be done by using a flue collection box behind the chamber and in front of the chimney. In the fastfire design the exit flue is restricted because of the direct connection into the chimney.

If the chimney cross section is made much larger than the inlet and exit flues in a natural draft kiln, tapering of the chimney must be done to ensure proper draft.

To make matters simple without jeopardizing the kiln design, make the inlet and exit flue areas and the chimney cross-section area all equal, with the chimney point of entry slightly smaller. It is far better to make these areas too large than too small, for they can easily be altered by plugging them up.

When using pressurized gas as a fuel, the inlet flue area should equal the exit flue area. An example: For an updraft gas kiln with 10 bottom burner ports with 2 1/2" diameters (inlet floor flues) which will equal approximately 4 9 square inches per hole or a total of 49 square inches, the exit flue in the arch should equal approximately 49 square inches. See Fig. 3-12. This is a safe rule of thumb to use, remembering in the case of a downdraft or pseudo downdraft one can block the exit flue. In the updraft the exit flue or
WOOD GUILDELINE: GROUNDHOG RATIO 4 TO 1

Fig. 3—12:

Flues (if two holes are used) can be made smaller by about 5 percent, but the option to enlarge if needed is possible. Remember, making a hole smaller is a whole lot easier than enlarging.

For a downdraft or crossdraft kiln using pressurized gas (forced draft), the inlet flues can be the size of the burner tips or slightly larger since the oxygen is supplied through the burner with secondary air pulled in around the burner port hole. In most cases, the inlet flue will be brick-size then reduced in size to add adjustability to the flue. If a combination of wood was to be used also, then an auxiliary air source must be provided. Exit flues should be built brick-sized (can be reduced in size if needed) and follow the natural draft relationships from flues to chimney. The difference with forced draft is that the height of the chimney is reduced by at least 25 percent.

PRINCIPLE 4

The taper of a chimney controls the rate of draft. Tapering reduces atmospheric pressure and increases the speed of draft, thereby controlling the rate of draft, which ideally should be 4 to 5 feet per second for natural draft kilns. The draft rate is measured periodically throughout the firing of the kiln, and, in the beginning, it will be very slow. The 4 to 5 feet per second is the rate of draft at most efficient operation, usually after 1,093°C (2,000°F) in cone 10 kilns. The draft rate measurement in feet is determined by the inside circumference of the chamber up the front wall, over the arch, down the back wall, through the flues and up the chimney (which is 45 feet in Fig. 3-13). For this kiln to fire at the proper draft rate, gases would take about 10 seconds to travel from X to Y. One way to determine the draft rate is to throw an oily rag into the firebox and count the number of seconds it takes for the smoke to come out the chimney. If it is too slow, tapering the chimney could increase the rate. A kiln chimney that is between 16 and 20 feet, with a base section of 12” x 12”, would normally taper to a minimum of 9” x 9”. In a natural draft kiln, seldom would a chimney be less than 9” x 9” at its base cross section.

PRINCIPLE 5

For natural draft kilns there should be 3 feet of chimney to every foot of downward pull, plus 1 foot of chimney to every 3 feet of horizontal pull. The height of the kiln chamber in Fig. 3-11 is 6 feet. Therefore, there are 6 feet of downward pull (dp); and for every foot, 3 feet of chimney are added: Thus, 3 x 6 = 18 feet of chimney. Then add 1 foot of chimney for every 3 feet of horizontal pull (hp), which in Fig. 3-14 equals the chamber width (5 feet), plus 1 foot of collection box, plus a 1-foot-wide chimney, totaling 7 feet. Thus, 7 = 2.3 feet; added to 18 feet, we find that this kiln requires a 20.3-foot chimney. To calculate chimney height for any natural draft kiln chamber: When using pressurized gas, the draft is forced and does not need the same height requirements as natural draft does to pull the draft through the kiln.

Fig. 3—13: Inlets and outlets must be approximately equal.

Fig. 3—14: An updraft gas kiln must have equal inlet and exit area.
PRINCIPLE 6

Chimney diameter is approximately one-fourth to one-fifth of the chamber diameter. If a chamber is 5 feet in diameter, then the chimney must be at least 1 foot in diameter. This principle, when used with Principle 3, can give a more specific chimney dimension for natural draft kilns.

PRINCIPLE 7

A tall chimney increases velocity inside the firing chamber. Too high a chimney can cause irregular heating by pulling the heat out of the kiln, not allowing it to build up within the chamber, thereby prolonging the firing. On the other hand, too short a chimney can protract the firing by decreasing the draft rate, which allows build-up in the firebox and does not pull enough oxygen into the kiln to allow proper combustion for temperature increase.

PRINCIPLE 8

The height of the chimney of a chamber kiln should be equal to the slope of the kiln. This is a useful guideline for determining minimum chimney height for a chambers kiln. To line up the chimney height, place a line along the chamber tops as shown in Fig. 3-15.

![Fig. 3-15: It requires 10 seconds for gases to travel from x to y (45 feet) in this kiln.]

PRINCIPLE 9

Critical areas of a kiln should be planned and built to be altered easily. If in doubt as to flue sizes, grate area, or chimney size, bigger is better. Plugging excess space with bricks is an easy matter. Also, for ease of construction, all dimensions should be based on the standard 9” x 4 1/2” x 2 1/2” brick, or the large standard, 9” x 4 1/2” x 3”. Perhaps 80 percent of the time, normal flue dimensions will be one brick standing on end (9” x 4 1/2”). These should be spaced 9” apart.

There will be no uncorrectable problem in the kiln if you remember to make flues adjustable, planning so that you can add or knock out a brick, make the chimney entrance flue adjustable, and build the chimney so that the height is readily adjustable.

HIGH-ALTITUDE ADJUSTMENTS

Building a kiln at high elevations necessitates adjustments to compensate for decreased oxygen per cubic foot of air. The difference is very apparent in hot desert elevations over 3,800 feet, and in mountain elevations from 5,000 to 10,000 feet. Outside air temperature, as well as elevation, has a direct effect on the amount of oxygen present. For instance, in Aspen, Colorado, the elevation is about 8,600 feet. However, at an outside air temperature of 22°C (72°F), the density of oxygen per cubic foot of air is equivalent to the amount found in air at 10,000 feet. Thus, kiln firing is more efficient at night, when the air cools and becomes denser, and more oxygen is present.

There are five steps in the procedure for making appropriate alterations to a natural draft kiln to compensate for high altitude and low air density.

1. Design the kiln according to standard principles, figuring out the chimney diameter, the inlet and exit flue sizes, and the chimney height.

2. Increase the chimney diameter by roughly 50 percent (so it works into the closest bricklaying combination). Thus, a chimney with a diameter of 9” would be increased to a diameter of 13 1/2” (Fig. 3-16).

![Fig. 3-16: Three feet of chimney length are added for every foot of downward pull, plus 1 foot of chimney for every 3 feet of horizontal pull: A, chamber; B, flue collection box; C, chimney.]

Fig. 3-17: Slope of the kiln determines chimney height.
**DIVISION OR COMMON WALLS**

A division wall is the common wall between two chambers. In a normal chamber wall, the temperature drops from the inside out, whereas a common wall may be subject to hot-face temperature on both sides. Thus, the division must be made of good quality refractory material. The common wall also supports the thrust of two arches (Fig. 2-14).

![Diagram of division or common walls](image)

*Fig. 2-14: A common wall supports the thrust of two arches and has two hot faces.*

It is good practice to build common walls 4 1/2" greater in thickness than the ordinary kiln wall; and a common wall should never be less than the width of the two skewbacks used.

**ARCHES**

**SPRUNG ARCHES**

Kiln arches perform two duties — forming roofs for the kiln chamber and forming doors and openings. Sprung describes the arch of a cylinder, and is the most common arch used in kiln building.

The arch rests on a skewback on both ends. Skewbacks determine the arch rise and tie the arch to the wall (Fig. 2-15). The force of the arch is down and out against the walls. If the skewbacks fail, the arch will move; therefore, the walls and skewbacks must be rigidly constructed. Standard sizes have been developed for arch, wedge, and key bricks, because dense firebricks are molded to size and fired, thus they cannot be easily machined. These special sizes are called No. 1, No. 2, and No. 3, and, when used by themselves, turn a circle. Arches are built using a combination of No. 1, 2, and 3 bricks with straights to turn almost any given circle. For the combinations of arches and straights in a given radius, see Estimating Firebrick Archs in Appendix.

The following list gives shapes and combinations of brick for the arch thickness specified:

- **4 1/2"**: Arch brick, or combination of arch and straight.
- **6 3/4" or 7 1/2"**: Large 9" arch, or combination of large 9" arch and large 9" straight.
- **9"**: Wedge brick, or a combination of wedge and straight. (Construction of key brick, or combination of key and straight, is not common, as the load is placed on the narrow face. This construction is only used when special conditions make it desirable.)
- **Over 9"**: Necessarily constructed of special wedge brick. However, 13 1/2" wedge bricks are standard from some manufacturers.

There are four major types of sprung arches: Bonded arches, ring arches, ribbed arches, and straight arches.

*Bonded arches.* The bonded arch is the most commonly used arch and is considered the best. The joints are staggered, tying the whole arch into a single unit (Fig. 2-16). If one or several bricks fail in a bonded arch, the bricks on either side absorb the load and the arch remains in place.

![Diagram of bonded arch](image)

*Fig. 2-16: Joints are staggered in a bonded arch.*

*Ring arches:* The ring arch is, as the name implies, one where each row of bricks across the arch is a ring of brick (Fig. 2-17). If one brick in the ring fails, the whole ring drops. It is difficult to replace a ring of brick. I used a ring arch on a chamber kiln and found that, during firing, the rings expanded open almost 1/2". Perhaps if the kiln had been tied together with steel, it would have helped. A bonded arch, however, doesn't have this problem. The main advantage of a ring arch is the ease of laying, especially when using a combination of standard shapes.

*Ribbed arches:* The ribbed arch is primarily used in open-hearth furnaces. The ribs give the arch stabil-
The important factor in using straights to make a sprung arch is to set the corners of the brick carefully (see Fig. 2-19, point A). Brick 1 is laid onto the arch frame. The inside edge of brick 2 must be above and touching the outside edge of brick 1. In other words, each brick acts as a lip for the brick on top of it. The arch is laid from both sides simultaneously, then the key brick is cut to fit. The arch is sprung off the form by starting at the bottom and working up both sides, driving wedges (bits and pieces of small refractories) into the gaps between the brick rows and spreading them apart, while driving the bottoms into a tighter fit. If, however, one over wedges or drives too big a wedge too deep, it will part the bricks on the bottom. This could also result in weakened brick. When mortaring the arch bricks, care should be taken to apply the mortar in a wedge form, thus helping to set up the proper wedge.

**Fig. 2-20:** Applying mortar to form a wedge.

The key brick must be pounded down below its neighboring bricks, thus ensuring a strong key (Fig. 2-21).

**Fig. 2-21:** The key should be forced below neighboring bricks.

**SUSPENDED ARCHES**

A suspended arch is mechanically held together and supported in place, and does not tie directly into the side walls. The support is usually a metal framework fitting into holes or grooves, or around specially shaped bricks, and held together by rods, pipe, tee bar, and so forth (Fig. 2-22). The most common thicknesses for suspended arches are 4 1/2" and 9".

The advantages of using a suspended arch are readily seen in top-loading electric or gas kilns. Repair to these arches is quite easy, unless sidewall bracing is required. Also, it is easy to accommodate thermal expansion, both horizontally and vertically, which reduces break-causing stress in the bricks.

**Fig. 2-22:**
**Fig. 2—22:** Metal framework for a suspended arch.

The disadvantage is that it usually costs more for the additional metal framework and connection rod assembly than is the case with a sprung arch.

**CORBEL ARCHES**

A type of arch seldom mentioned is the corbel. This particular arch can be used to span portholes or flue holes where other lintel shapes are too small (Fig. 2-23). Use the corbel arch to span up to 24".

**Fig. 2—23:** Corbel arches can be used to span flues or portholes.

I have seen small, 10- to 16-cubic-foot kilns with corbel arches. This is not a good practice for the following reasons: (1) structural instability; (2) the uneven inside surface causes irregular heating and flame turbulence; (3) bricks are subject to greater erosion; and (4) the design is generally poor.

**FRAME CONSTRUCTION**

To begin building an arch, one must have a wood frame, which can be constructed in a number of ways. The first method produces a one-use arch form that is good for freeform arch construction (Fig. 2-24). Another method produces a reusable arch form for standard skewback arches (Fig. 2-25).

To make an arch support for a standard skewback arch using a featheredge, you need to know two things: the span (the distance between the two supporting walls) and the rise of the arch (Fig. 2-26). A featheredge will give a rise of 1 1/2" per foot of span.
Use this formula to find the radius of the circle:

\[ 1.0625 \times \text{span} = \text{radius} (r) \]

A catenary arch usually has a rise-to-span ratio that exceeds the 1 1/2"-3" range considered good practice. The catenary arch is formed by first deciding upon the span, then forming the curve with a perfectly flexible, inextensible cord suspended by its end (Fig. 2-27). The catenary arch is self-supporting. It contains the walls and sprung arch all in one curve.

**Fig. 2—27: Building a self-supporting catenary arch.**

**DETERMINING ARCH**

Because a standard featheredge can be used as the skewback, the minimum rise for an arch is usually 1 1/2" per foot of span. Anything less can result in structural difficulty. The maximum rise has generally been set at 3" per foot of span. The greater the rise of the arch per foot of span, the sturdier the arch will be. I have raised an arch with a 6" rise per foot of span with very good results, so no hard-and-fast rule can be applied.

When using dense bricks, standard-size arch, wedge, and key brick can be used in combination with straights to turn any given radius. Insulating bricks, however, are sized and shaped after firing to a given radius, thus simplifying construction and increasing strength because of the radius involved. Standard shapes can be used, which reduces the cost.

**DOMES AND CROWNS**

Domes and crowns differ from sprung arches in that an arch describes a portion of a cylinder, while a dome or crown describes a portion of a sphere. A crown describes two sphere arches that meet at dead top center, but originate from different axes. A dome has a single radius (See Fig. 2-28). A crown generally has a flue in the top, while a dome is usually plugged. The rule of thumb for the rise of domes and crowns is 2 1/2"-3" per foot of span. Bricks are laid the 4 1/2" way.

**Fig. 2—28: A dome or crown describes a portion of a sphere.**

**EXPANSION JOINTS**

During the heating and cooling of a kiln, firebrick will expand vertically and horizontally along a wall, and at a 90° angle to the wall. Each foot of refractories along the wall will expand from 1/16" to 3/32" when heated and cooled. If a kiln is built without an allowance for expansion, the bricks will destroy themselves through mechanical and structural spalling. In many cases, kilns with steel frameworks have been built with no tolerance for expansion and contraction. The walls have buckled, sagged, and cracked, and the frame has bent and bowed.

In free-standing kilns, such as a chamber kiln, expansion joints are not used, except perhaps when the side wall is fitted to the arch. Corner joints and joints where the common wall ties into the side wall are mortared with just a bit more space between bricks. The walls are then free to expand as a structural unit, since they are not tied by steel. If such a kiln is reinforced with tie rods, the rods should be bolted taut when the kiln has reached temperature. This allows for normal expansion.

In an enclosed steel frame, or when a kiln is backed by rigid steel, the bricks must be given proper expansion joints (Figs. 2-29 and 2-30).

Figure 1/16” gap per 1 foot of wall. If the kiln wall is 5 feet long, then the gap should be 5/32” on each end. However, do not have the expansion joint going through the wall but built into the corner joint (Fig. 2-31).

In an insulating firebrick kiln within a steel framework, the expansion joint can be eliminated.
Chapter 4
Crossdraft Kilns

Crossdraft kilns have a flame movement from the inlet flues on one side of the kiln chamber to exit flues along the opposite side. The four most common types are: the single-chamber kiln, the chamber kiln, and the tube kiln (Fig. 4-1).

![Crossdraft Kiln Diagrams](image)

Fig. 4—1: The four most common crossdraft kilns.

Crossdraft kilns originated in the Orient. The exact location and time is impossible to determine, but it is probably safe to assume that China, Korea, and Japan simultaneously developed similar crossdraft kilns known as bank or hole kilns. The hole kilns were in use during the Asuka period in Japan, the Sui period in China, and the Silla period in Korea. In Japan they were called anagama; ana meaning hole or cavity and gama meaning kiln.

The late Tomimoto Kenkichi related his theory on the development of the anagama. Through the centuries, potters realized that the more enclosed the primitive pit kiln became, the hotter the firing and the more durable the pottery. Firing temperatures were increased by banking up the sides with clay as shown in Fig. 4-2.

![Enclosed Pit Kiln](image)

Fig. 4—2: An enclosed pit kiln, forerunner of the anagama.

While the potters around the eastern Mediterranean Sea (Asia Minor) and the Middle East built the walls up to form a simple beehive updraft kiln, Oriental potters proceeded in a different way. Their pottery villages were always built upon the clay source. (China, Korea, and Japan have vast amounts of stoneware clays ready to use right out of the ground, while in comparison, the Middle East has very little usable clay.) Utilizing the banks and hills of clay, they hollowed out holes large enough for a man to crawl into. The main cavity was widened and then tapered back into a chimney flue leading up to the surface. After the hole and cavity were hollowed out, the firebox, floor, and walls were shaped in the clay and allowed to dry. A small fire of increasing intensity was built in the entrance or firebox and allowed to burn for weeks until the inside walls were bisqued. This transformed the chamber into a monolithic structure.

When the anagamas were fired, glaze deposits (wood ash slag) formed on the chamber walls and roof. As the kilns became hotter and were fired longer, the accumulated wood ash slag dripped onto the pots. The resultant marking was considered a defect at first, but in time it came to be appreciated, and became the first style of wood ash glazes.

As the anagama developed, the kiln became too large to be dug out without breaking through the ground. Thus, according to Tomimoto, the single chamber kiln matured into the tube or bank kiln. The art of brick making and the design of the conical tatami bricks made possible the spanning of an arch and the elevation of half the kiln above the surface level.
Chapter 5

Downdraft Kilns

A downdraft kiln can be defined as a kiln which has draft movement starting with the inlet flues, circulates in the chamber, passes down through floor exit flues, and flows out the chimney (Fig. 5-1).

![Diagram of air flow in a downdraft kiln](image)

Fig. 5-1: Air flow in a downdraft kiln.

Downdraft kilns probably originated in Europe, perhaps in Germany after 1800. European porcelains had their beginning in the early 1700s when a man named Better in Germany developed a kiln that could reach the desired temperature of 1,300°C (2,372°F). For the next 100 years, considerable improvements in refractory materials were made, especially in saggars (which also played an important part in the Kyoto chamber kiln development). Coal and coke were introduced as a fuel, and new methods in kiln construction were developed to meet the higher temperatures. These included improved fireboxes, chimneys and draft systems that were being experimented with to increase efficiency. Better kilns, which would fire evenly, produced a more uniform quality and, of course, save on fuel and losses, were needed to meet the demands of industrialization. Thus the downdraft kiln was developed to replace the European bottle updraft kiln (see Chapter 6).

The downdraft kiln design offered inherently even temperature with the ability to control temperature distribution and atmosphere, economical fuel consumption, and the ability to expand the kiln to an extremely large size while retaining the firing characteristics of a smaller kiln.

The advent of the European downdraft kilns in Japan followed the Meiji Restoration in 1868. An Austrian chemist, Dr. G. Wagener, was a guest of the government and responsible for the establishment of national and prefectural ceramic research and training institutes in Japan. According to Tomimoto, he sent one of his students to Europe to learn about downdraft kiln construction and production methods. Upon the student's return to Japan, the production methods and downdraft kilns were introduced to the Seto and Tajimi areas in Gifu prefecture.

**Proportional Relationships of Early Natural-Draft Downdraft Kilns**

1. The height-to-width ratio is very important for satisfactory even firing (see Chapter 3, Principles in Kiln Design, Rule 1).
2. A downdraft kiln's proportional dimensions or multiples are as shown in Fig. 5-2 for natural draft.
3. The chimney must be placed at a right angle (90°) to the firebox inlet flues to provide a proper draft pull down through the middle of the chamber.

![Diagram of proportions of early downdraft kilns](image)

Fig. 5-2: Proportions of early downdraft kilns. *Variance on 2m x 2m chamber to 1.7m x 1.7m with same chimney relationship.
4. All rules in Chapter 3, Principles in Kiln Design, must be followed.

The proportional dimensions given here are based upon the analysis of Oriental kilns. These basic dimensions should be used as a starting point for designing a natural-draft downdraft kiln. In comparison to the nine principles of kiln design in Chapter 3, there are two minor discrepancies found in the proportional downdraft kiln dimensions.

First, Rule 5, concerning chimney height, states that for every foot of downward pull, add 3 feet of chimney; for every 3 feet of horizontal pull, add 1 foot of chimney. In comparison with downdraft chimney proportions, this would add an extra 1 1/2 ft. to the chimney. The two relationships between kiln chamber and chimney are so close that the proportional relationship can be used as the minimum and Rule 5 the maximum. In the case of forced draft, the chimney height can be reduced by about 1/4 or until a draft rate of 4 to 5 feet per second is achieved.

Second, Rule 6 states that the chimney diameter is 1/4 to 1/5 of the chamber diameter while the proportional dimensions give the chimney diameter as 1/2 of the chamber diameter. The reason for specifying such a large chimney base is that it will be able to accommodate additional kilns. This rule has generally been retained even though normally only one kiln is ever built. Remember, there is greater safety in having an oversized chimney diameter. To compensate for the extremely large bottom diameter, the chimney entrance flue is greatly restricted and the taper of the chimney is 2 1/2 to 1. If Rule 6 is followed, there is a saving in the number of bricks used in laying the chimney and the construction difficulty in tapering the chimney is eliminated. Thus, a more realistic proportional dimension can be derived that would be more in tune with modern forced-draft kilns.

Proportional relationships of modern forced or natural-downdraft kilns are shown in Fig. 5-3.

![Figure 5-3: Proportions of modern downdraft kilns. For a 6 x 6 foot chamber, the chimney base must be at least 12" in diameter, the top 8" in diameter, and the height at least 20'. The distance between chamber and chimney can be smaller than 3' without affecting the chimney size.](image)

![Figure 5-5: Cross section and floor plan of the Kato kiln.](image)

Notice that the chimney taper is 1 to 3/4 or 1 1/4 to 1. If forced-draft burners are used, the height of the chimney can be reduced by as much as 25 percent, but I know of no certain rule. The only way to determine this is to fire the kiln and adjust.

**DOWNDRAFT TAJIMI STYLE KILN**

Kenji Kato pottery, Tajimi, Japan. Mr. Kato's coal-fired downdraft kiln is approximately 250 cubic feet in size (Figs. 5-5). The kiln is fired in 50 hours to 1,300°C (2,372°F) in a very heavy reduction atmosphere and allowed to cool for three days or more. The firing cycle is quite slow due to the extreme thickness of the kiln walls and the fact that there are only two fireboxes. After 1,090°C (2,000°F) is reached, the reduction stoking rate is 10 to 12 shovels of coal every 20 minutes, while an oxidation stoking rate is 3 to 4 shovels every 20 minutes.
Chapter 6
Updraft Kilns

A kiln that has a draft that enters through inlet flues at the bottom of the kiln, passes into the chamber, and exits through flues in the arch or dome, is an updraft kiln (Fig. 6-1). Over the centuries, primitive potters realized that the more enclosed the pit kiln became, the hotter the firing and the more durable the pottery. This was accomplished by banking up the sides with clay. These early potters found that, by putting holes close to the bottom of the pit (probably to force more fuel in), the combustion was greatly improved and higher temperatures attained. Banking the walls and placing the air and stoke holes at the bottom of the pit were practices that led to the early wall updraft kiln. Fig. 6-2 shows the basic improved pit kiln, with a space above the pottery to form the stoke and air-supply holes around the perimeter of the wall.

The improved pit kiln is used today in such places as Spain, Nigeria, Mexico, and in pottery villages throughout Africa, India, and South America. Sticks, grass, dung or a combination are used as fuel. The walled area is lined with fuel packed firmly into the space between the pots and wall. The pots are piled and mounded to form a dome shape. The dome may be made of broken shards, covered with dirt and straw, or plastered with a clay-straw mixture. Vapor and exit flue holes are left in the dome. The kiln is fired and stoked until the dome is red hot. In some, more fuel is thrown over the dome and burned before the kiln is left to cool.

When primitive kilns reached this stage, the next step to increase temperature was to get the fire under the pots to allow the flames to move up through them. This created a controlled updraft kiln. Potters around the eastern and southern Mediterranean Sea, and across the Middle East to North Africa and into Spain, kept building the walls higher and introduced the firebox directly under the pottery, creating a simple beehive updraft kiln. The first of these kilns was quite small because of the problem of spanning the firebox pit area under the chamber.

This problem was solved, I believe, by potters somewhere near Niger, where the baobab tree grows. The baobab has a thick trunk, with the main branches separating at a common height around the trunk. The structure of the baobab was imitated in local architecture. Branches separating off the central trunk supported ceilings. The imitation baobab construction was made of flexible branches, small trunks and bundles of faggots tied together and shaped into the support structure. This was then reinforced with clay and plastered with clay plaster. Local potters borrowed this technique from builders and constructed a baobab-type structure to hold up the kiln floor. This umbrella-style kiln spread to other areas, including Spain.

UMBRELLA KILN

The umbrella kiln is still being fired in Movéros, Spain, today. The kiln consists of a small chamber, about 5' in diameter, and an umbrella floor built off a central trunk with the firebox below (Fig. 6-3 and photo 1 and 2). Granite rocks are mortared together