BTU ENGINEERING CORPORATION
ESQUIRE ROAD, NORTH BILLERICA, MASS. 01862 U.S.A.
TEL. 617-667-4111

TECHNICAL BULLETIN 221

FURNACES FOR ELECTRONIC PROCESSING

Technical Data

Thick film pastes are roughly divided into two groups—the noble metal compositions fired in air, and the base metal pastes that require neutral or reducing atmospheres. BTU Engineering Corporation offers four furnace lines to meet the full range of thick film requirements.

The VQ Series furnace with quartz muffle is ideal for air firing noble metal thick film pastes; the Cu-N Series Transheat® furnace with inconel muffle is designed for precision firing of copper and nickel in non-oxidizing atmospheres; the MQ Series multi-atmosphere furnaces can be used alternately with air and neutral or reducing atmospheres (one at a time) and, lastly, the new MG Series furnace allows two atmospheres to be used at the same time and features a quartz muffle in the high heat section.*

Since air firing of thick film circuits is still the most widely used process in the industry, this bulletin will discuss the VQ Series furnace initially. As the MG, Cu-N and MQ Series have many functions and features in common with the VQ, only their differences will be broken out further in the text.

THE VQ SERIES

Atmosphere Control

- Complete exhaust of solvents and binders
- Counterflow atmospheres prevent effluents in burnout section from entering sintering section
- Preheated and individual flow control of atmosphere for both burnout and sintering sections

V-Bottom Quartz Muffle

- Clean, oxide-free environment
- Excellent temperature uniformity, low thermal mass
- Elimination of thermal lag and metal oxide contamination due to metal hearth
- Reduced friction—belt rides directly on quartz muffle, increasing belt life and reducing friction by 50% as compared with a metal muffle

Temperature Control

- Fused silica protection tubes minimize thermocouple aging, provide optimum thermal response
- Accutrol 128 solid state temperature controllers are specifically designed and proven to meet the demanding requirements of precision conveyor furnaces
- All SCR "Power Prop" controls with zero crossover triggering
- Best cross-belt uniformity and thermal response under load to no-load conditions

Heating Elements

- Characterized heating elements meet specific zone requirements for optimum control
- Heavy gauge wire for lowest watt density and long element life

Insulation

- High Quality, graded insulation selected for thermal efficiency and long life without thermal degradation

*For metallizing and co-firing with moly manganese pastes, BTU offers pusher and walking beam furnaces which are not discussed in this technical bulletin.

Operation

- Display panel gives instant indication of furnace operating conditions
- Recorder (optional) stores out of the way for long-term monitoring, slides out and tilts up to convenient position for profiling and easy viewing

Muffle Material

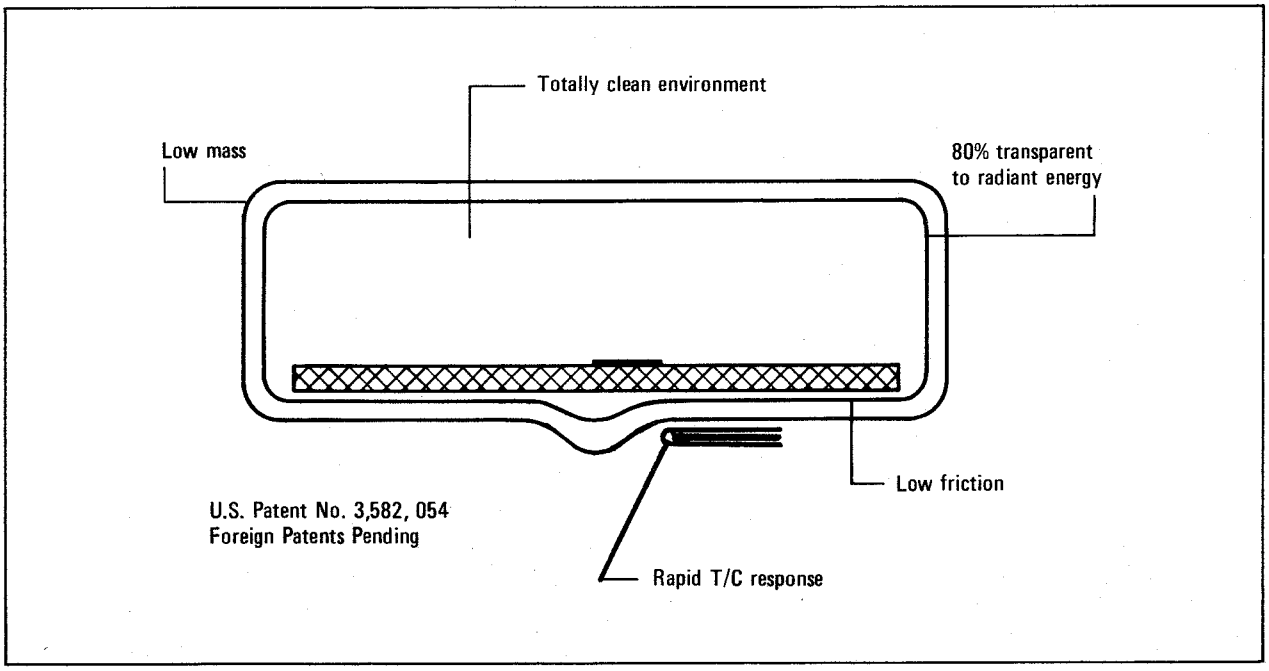
To minimize product contamination and provide a method of controlling the processing environment, furnace manufacturers use muffles of ceramic, metal or quartz.

Ceramic muffles are generally made of self-bonded silicon carbide, which has good temperature conductivity and high emissivity—in other words, a thermally efficient material. However, silicon carbide has considerable shortcomings in other areas. It is abrasive and will wear the belt flat in a relatively short time. In addition, the thermal conductivity of silicon carbide decreases with age and in proportion to the increase of crystabolite due to oxidation of the material. While silicon carbide muffles are suitable for pusher-type furnaces operating between 1200°C and 1400°C, BTU Engineering does not recommend them for belt furnaces operating below 1100°C.

Metal muffles provide long life and are more economical to fabricate than ceramic or quartz muffles, but their use is generally ruled out in oxidizing furnaces operating above 600°C due to contaminating metal oxide formation within the process area.

Fused quartz is the ideal muffle material for air-fired, thick film furnaces. Among its many advantages, the fused quartz muffle provides a clean, oxide-free environment, excellent temperature uniformity and immediate sensor response with little time lag. Of the three muffle materials, quartz has the most efficient heat transfer characteristics and is more than 80% transparent to radiant energy in the temperature range used for sintering noble metal pastes.

The complete advantages of fused quartz are best realized in thick film firing furnaces, where the patented V-bottom quartz muffle enables the belt to ride directly on the muffle. This unique design eliminates the heavy thermal mass of the conventional metal hearth, thus reducing the static mass of the furnace and increasing speed of response. By eliminating the metal hearth, this source of metal-oxide contamination is eliminated. (To avoid contamination of the atmosphere due to belt oxidation, BTU offers ultrasonic or brush-type belt cleaners.) The V-bottom quartz muffle provides fast thermocouple response, and minimizes friction between belt and hearth. The dynamic coefficient of friction of a conveyor belt on quartz is approximately half that of a belt on a metal hearth. Lower friction means less belt stretch and distortion and longer belt life at elevated temperatures.

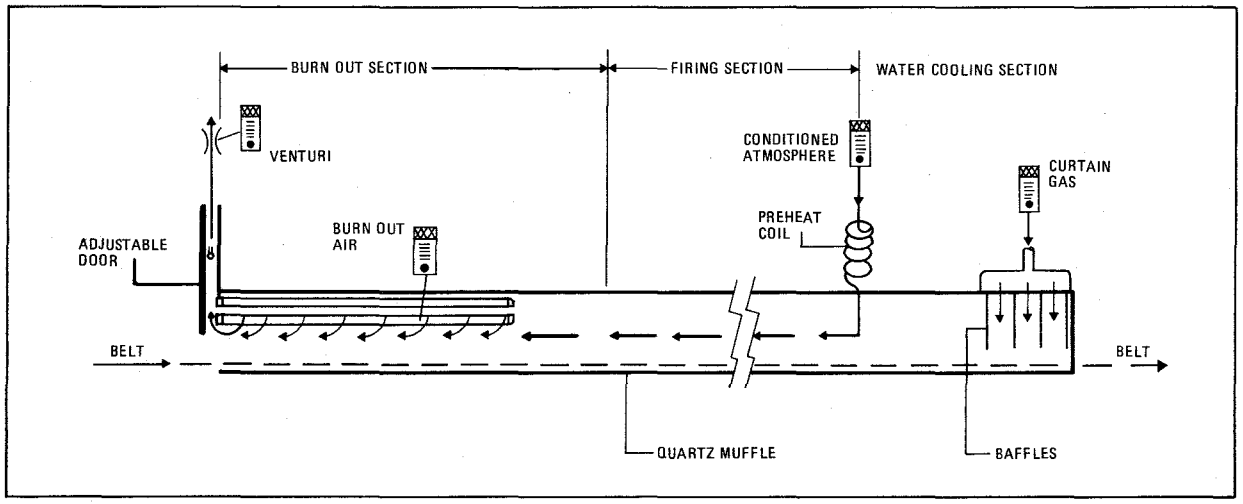


Atmosphere Control

Consistent results in thick film firing depend on effective control of the atmosphere system. A well designed atmosphere control system should:

- Separate the processing environment from the effects of the ambient
- Provide controlled flow of quality air within the process chamber
- Assure complete scavenging and exhaust of volatilized solvents and binders in the preheat section
- Separate preheat and high heat chamber atmospheres to prevent effluents from entering sintering area.

The following diagram shows how BTU's atmosphere control system satisfies these requirements.



Thermocouples

Thermocouple speed of response is an extremely important factor in determining temperature stability under fluctuating load conditions. In VQ Series furnaces, there is no heavy thermal mass, such as an inconel hearth plate, to separate the product from the thermocouples and prevent rapid response to changing loads.

Power Design

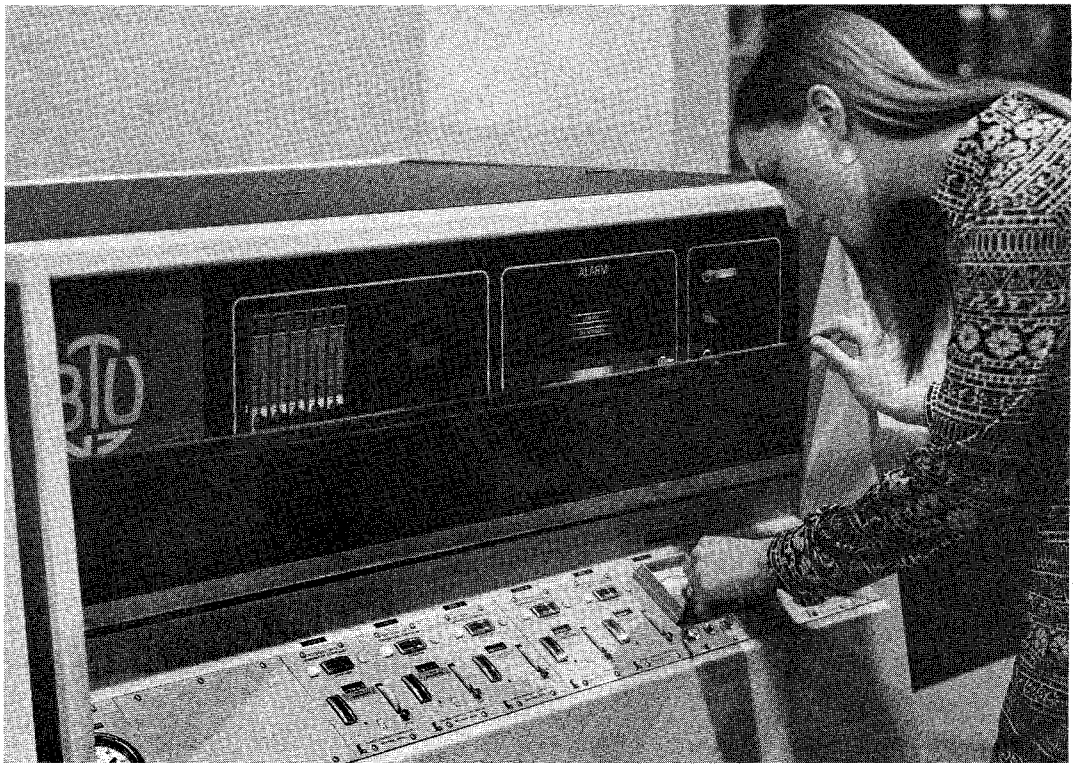
In order to achieve optimum control, a furnace should be designed with characterized heating zones. Power to each zone should be established by that zone's requirements.

Many manufacturers offer furnaces with so-called "modular" sections or elements, each with the same pre-determined power rating at a given voltage. Thus the power in each zone is identical and total furnace power is a function of the number of sections or elements supplied. When a 24" zone is required, for example, a standard element or module is used which typically has a power rating of 10 KW. Though satisfactory if applied to a zone requiring this maximum power, the same module applied to a zone demanding only one-half to one KW will be operating at 5 to 10% of its capacity, and is harder to control. To overcome this instability, insulation is usually reduced, increasing heat losses to the ambient and failing to efficiently utilize the power supplied to that zone—contributing to poor energy management.

Characterized element design allows the proper balance of heating capacity, enabling precise temperature control, and allows correct input rating, reducing operating costs. Modular elements will operate at above average watt density in demanding zones, and below average in slack zones, causing premature burnouts in the first case and wasting electrical capacity in the latter. Characterized element design divides load and wear evenly.

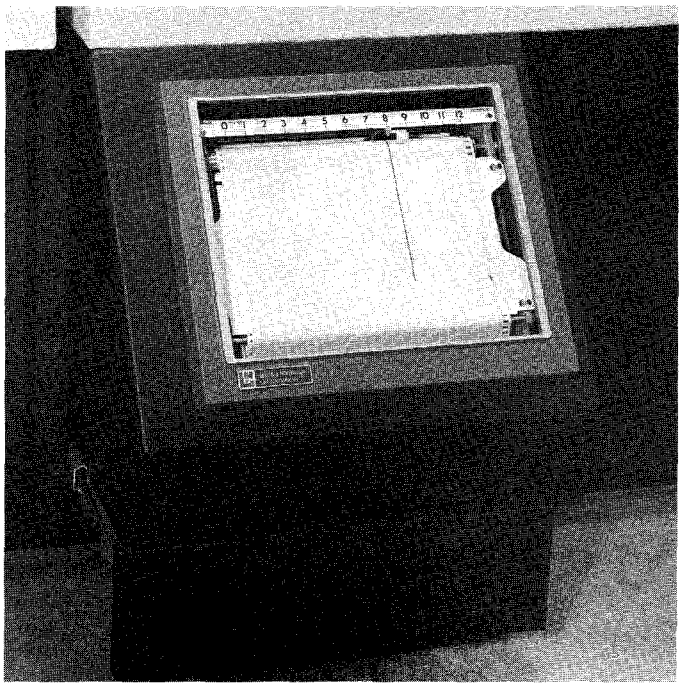
Operation

For ease of operation, controllers are mounted in an inclined console at convenient visual and operational level.

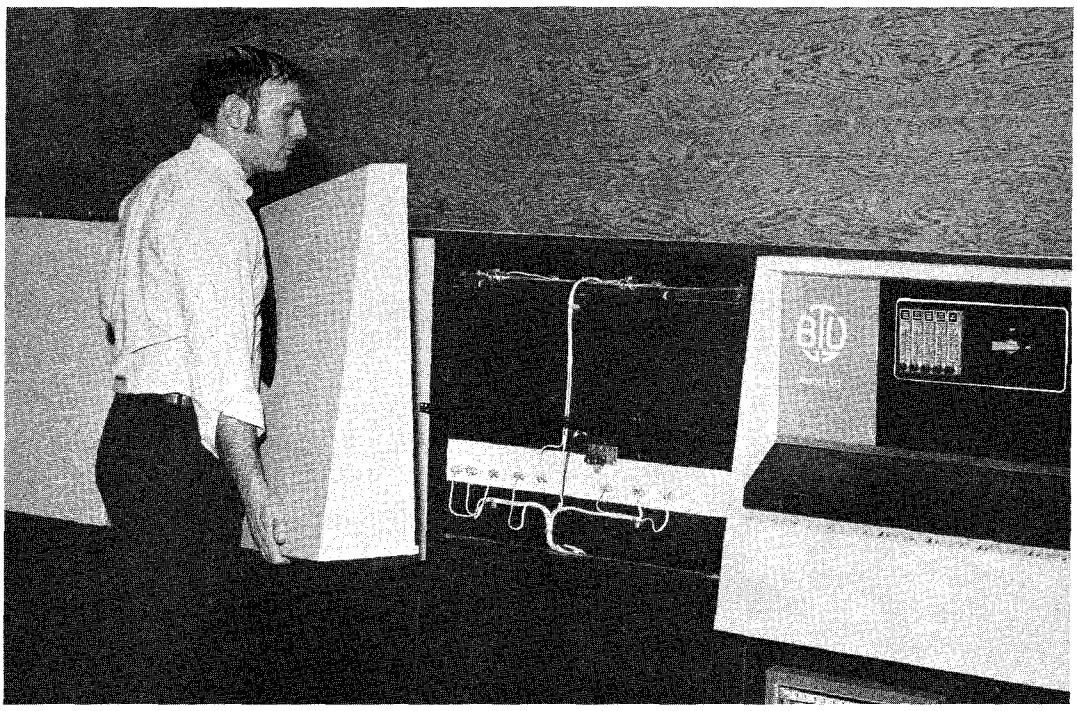


For ease of operation, VQ Series furnaces have all controllers mounted in an inclined console at convenient visual and operational level.

Blind controls such as zone trimming are located under a hinged panel where access is convenient but out of the way of idle fingers.



For long-term monitoring, the optional recorder stores unobstrusively under the control console and slides out at a 30° angle for convenient visual observation during short-term profiling.



Access panels are easily removed for convenient servicing of the furnace.

THE MG SERIES

Two atmospheres may be used at the same time in the new MG Series furnace, i.e., air in the burnout section to assure complete carbon removal, and up to 7% H_2 forming gas for safe sintering in the firing section. For noble metal firing, air may be used in both sections. Changeover of process atmosphere is simple, safe and fast.

These units feature a metal muffle preheat and quartz muffle firing section. The fused quartz muffle insures a clean process environment in air, excellent temperature uniformity and rapid sensor/control response.

Other features of the MG Series furnace include venturi-controlled exhaust for preheat section, entrance and exit atmosphere curtains, and eight flowmeters with loss of atmosphere pressure alarm. Burnout atmosphere can be directed counter to or with product travel. MG Series furnaces come in belt widths of 4, 8 and 12 inches.

THE CU-N SERIES

In order to process the new, base metal thick film pastes, BTU has developed a dual atmosphere furnace, designated the Cu-N, with built-in flexibility of temperature, atmosphere and process time. For optimum results when firing copper and nickel pastes, the product is burned out in air at 450-550°C, then fired in hydrogen or various forming gas mixtures at 900-1000°C. These critical process parameters are achieved with BTU's patented Heat and Gas Barrier, which makes it possible to obtain the necessary separation of both heat and reactive atmospheres between adjoining muffle sections.

The following excerpt from S.J. Stein and C. Huang's paper, "Screen Printing Techniques," presented at the 1973 Society for Information Display, emphasizes the value of this feature:

> Firing is best performed in a dual atmosphere furnace. The burnout zones can use an air, or nitrogen plus air, mixture in which the total oxygen content is lower than that of normal air. The resinous decomposition products should be swept out of the furnace without permitting them to go into the peak zones. A dwell time of 15-25 minutes in the temperature region between 300° to 550°C. allows for removal of the organic constituents. An efficient gas barrier allows good atmospheric isolation between the burnout zone and the rest of the furnace. Care must be exercised to avoid incomplete resin removal. Too rapid a firing cycle may trap carbonaceous residues in the film by allowing the glasses to soften, flow and form a surface "skin" in the peak zones. If this occurs while some carbonaceous material may still be present, dielectric properties may be impaired.

And George Lane of Electro Materials Corporation of America (EMCA) notes the growing importance of base metals in thick film firing:

> Probably the most interesting use of nickel today is not as a low-cost replacement for noble metal conductors, but for use in plasma displays. These displays, made by Burroughs, General Instruments and others, rely on the unique non-sputtering properties of nickel, not its low cost. It has opened up a new market area. As you know, we believe in multi-atmosphere furnaces. We have found that forming gas is usually reducing enough. Pure hydrogen or dissociated ammonia is not required. It does not harm, but is not generally required.

For large scale production of base metal circuits, the dual atmosphere furnace with inconel muffle and the BTU patented Heat and Gas Barrier is indispensible. The Cu-N Series furnace provides the capacity for burnout of binder materials without trapping carbon in the film. Once trapped during the fusion process, it will destabilize the film to the point of rendering it useless. At completion of the burnout phase, the sintering takes place in forming gas or nitrogen in the same furnace muffle, with the sintering section atmosphere separated by the BTU Gas Barrier (U.S. Patents #3,179,392; 3,041,056 and 3,138,372).

THE MQ SERIES

For the thick film processor concerned about his capability to fire conventional thick film materials in a clean, controlled air environment and yet be able to process base metal compositions as well, BTU offers a multiple atmosphere furnace designated the MQ Series. This type of furnace has a quartz muffle for air firing noble and conventional inks, and can be instantly converted to combustible hydrogen, dissociated ammonia, forming gas or nitrogen atmospheres for firing base metal compositions.

The MQ Series furnace offers maximum flexibility for the thick film circuit manufacturer—the opportunity to change processing techniques according to industry requirements and considerations of economy, the chance to perform research and trial runs, and the convenience of using the same equipment for related processes, such as package sealing, glazing and soldering.

The MQ Series will operate alternately in air or reducing atmospheres—a capability achieved through the implementation of the following features: A single-section, fused quartz muffle projecting from the furnace case at entrance and exit ends into sealing boxes. The seals joining the quartz muffle to the stainless steel entrance and exit sections are made of high temperature elastomers, are water-cooled and spring-loaded, and form an integral part of the entire gas-tight system. The entrance section is baffled, with curtains and N_2 provisions; the exit is baffled as well, has a water-jacketed cooling section, N_2 capacity and H_2-N_2 safety purge control system.