Energy Dominates in Job Costing for Vacuum Furnaces

By A. BRUCE CRAVEN, EIT, Vice President/Engineering & Plant
Solar Atmospheres, Inc., Souderton, PA 18964

Job costing can sometimes be a tedious task, however, it is a necessity if a business is to understand its true costs and predict its profits. Using a vacuum anneal heat treating cycle, as an example, costs can be identified by category, permitting a total cost to be calculated for the job. The seven specific topics covered are the initial cost of equipment, electric utilities, labor, process gases, fixturing, water cooling systems and maintenance.

The example involves a vacuum furnace (VFS model HL-50) with an installed cost (all utilities connected and ready to operate) of $350,000. The furnace characteristics are shown in Table I.

Table I Specifications for Vacuum Furnace Components and Parameters

225 kW hot zone power supply capacity
20°F/minute heating ramp rate @ 80% capacity
20 horsepower mechanical pump motor
75 horsepower gas recirculating fan motor
7.5 horsepower vacuum booster motor
18 kW diffusion pump heater
2 kW isolation transformer for furnace computer and controls
300 CF quench gas volume requirement for -5" Hg quench
$0.10/kW-hr electric utility cost

Equipment Cost

In order to capture the cost of the equipment, we will approach the purchase with zero money as down payment, i. e., the full amount financed over seven years at an annual interest rate of 10%. The payments will be made every month.

The monthly payment amounts can be arrived at by using the "uniform series" cost accounting formula which is:

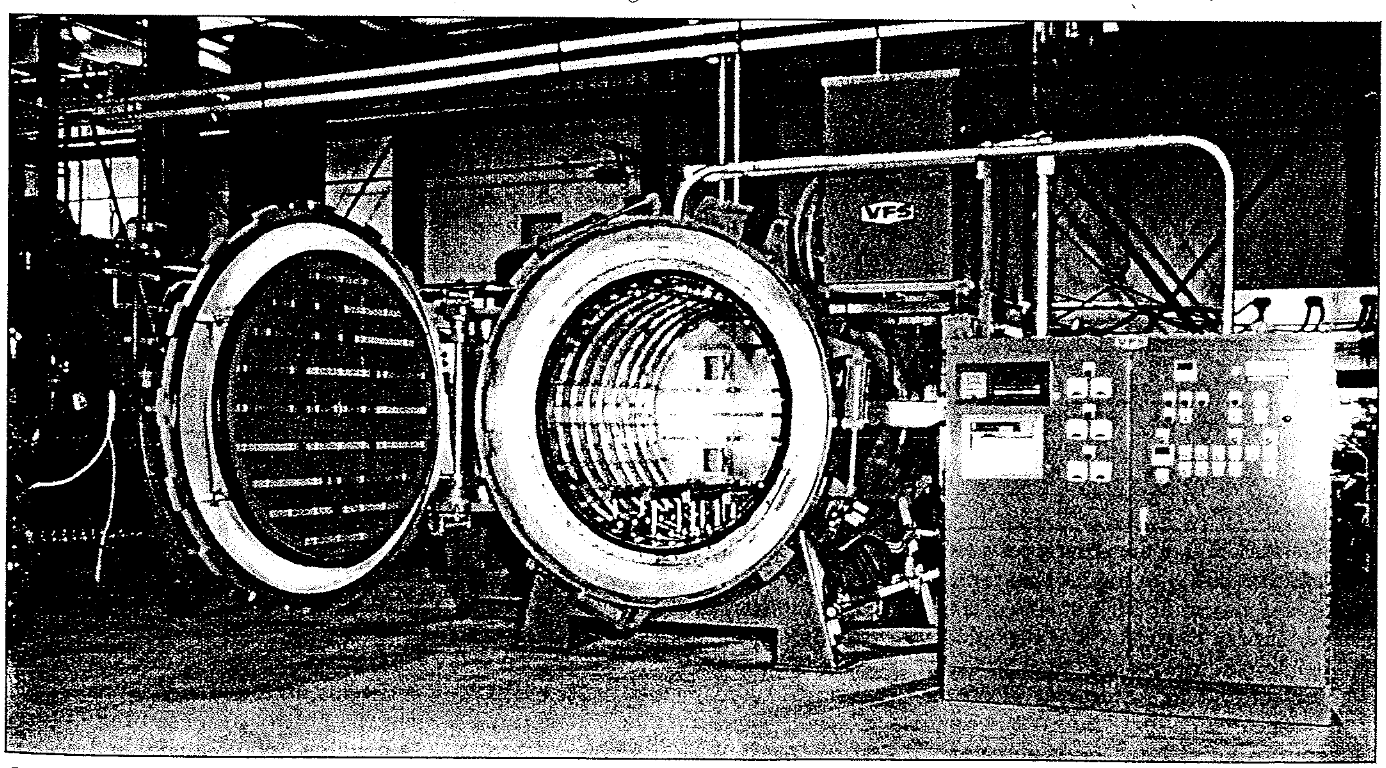
$$R=P * [i * (1+i)n] / [(1+i)^n - 1]$$

where

- R= monthly payment
- P= initial cost ($350,000)
- i= monthly interest rate (0.10/yr/12 mos./yr)
- n= number of payments (7 yrs * 12 mos./yr)

Putting the values into the equation, the monthly cost is calculated to $5,800. Annually that figure becomes $69,700.

Now that the annual equipment cost is known, it is necessary to determine



Determining the cost of a heat treating operation, with this type of vacuum furnace facility as an example, is described in this article, covering practically all of the aspects and parameters involved.

what its usage will be. For this example, consider that work will be 24 hours per day for 5 1/2 days per week. Including loading, unloading and other non-production (although full utilization), estimated non-productive time is four hours per day; also considered are two weeks per year for paid holidays and maintenance shut-downs. This translates into:

20 hrs/day * 5 1/2 days/week * 50 wks/year=5500 hrs/yr of productive up-time.

The fixed cost per hour to operate the furnace is calculated as:

(Financed cost/yr)/(5500 hrs/yr)

Therefore,

($69,700/yr)/(5500 hrs/yr)=$12.65/hr

The heat treating cycle considered for this furnace operation is a 1 1/2 hour ramp in 100 scfh partial pressure nitrogen to 1900°F, a one half hour soak at 1900°F maintaining the partial pressure and a subsequent 2 hour quench with nitrogen.

Electric Cost

In considering the cost of electricity, an assumption can be made that one horsepower is equivalent to one kilowatt. The electric cost can be calculated in $/hr by the following formula:

$$E_c = P * r$$

where

E_c = Electric cost in $/hr
P = power rating of the equipment in kilowatts (kW)
r = rate paid in $/kW-hr

The assumed energy requirements for the vacuum furnace at given temperatures are listed in Table II. These values are approximate but of reasonable accuracy.

Table II Power Supply Rating at Various Temperatures

SOAK TEMPERATURE	% POWER SUPPLY RATING
1000°F	25%
1500°F	40%
2000°F	50%

Determination of the electric costs for the cycle begins with the heat-up ramp involving maximum limit of 80% of the power supply capacity. It is desirable to maintain output maximum at 80% to keep electric demand down. Electric utilities charge not only for kW-hr consumption but also for peak demand. Cascading heat up ramps of various furnaces and keeping their individual power consumption at modest levels are key to preventing a runaway electric demand.

Heating from 100°F (ambient) to 1900°F is a 1800°F temperature rise at a 20°F/minute ramp rate. At 80% output of the 225 kW power supply and $0.10/kW-hr electric power, the cost amounts to:

0.80 * 225 kW * $0.10/kW-hr = $18/hr and,

(1800°F) / (20°F/minute) / (60 min/hr) = 1 1/2 hrs

Therefore 1 1/2 hours of heat up ramp at $18/hr gives the heat-up electric costs of $27.

The soak, the next part of the cycle, will be maintained at 1900°F for one half hour. Knowing that maintaining 1900°F requires 50% of the power supply rating, and the soak duration is one half hour, cost of soak is calculated as:

0.50 * 225 kW * $0.10/kW-hr * 1/2 hr = $5.65

To calculate the electric costs for cooling, recall that 1 horsepower is equivalent to 1 kilowatt and also from Table I that the gas recirculating blower motor is 75 HP. Also established is that the cooling cycle will require two hours, hence, the blower motor will operate for that time. Using the same formula used previously where electricity for the fan (blower) is equal to the multiplication of the power rating, electric rate and number of hours in service, the cooling cost is:

E_{fc} = 75 kW * $0.10/kW-hr * 2 hrs = $15

In addition, there are several small electric consumers and their load must be summed, Table III, to calculate their cost.

Table III Power Consumption by Various Components

Control transformer	2 kW
Vacuum booster motor	7.5 HP
Diffusion pump heater	18 kW
Mechanical pump motor	20 kW
TOTAL	47.5 kW

Since the total cycle length is 4 hours, the total miscellaneous electric cost is:

4 hours * 47.5 kW * $0.10/kW-hr = $19

The summary of electric costs for this cycle then becomes heat up ($27.00), soak ($5.65), quench ($15.00), and misc. electric ($19.00) for a total of $66.65.

Labor Cost

The overhead figures that are added to the direct labor rate vary from plant to plant. Generally, companies use a gross margin multiplier on top of the employees direct labor rate. The alternative is a calculated rate/hour for each employee to be added to the respective direct labor rate. Either option is acceptable. Because of the variables, only direct labor cost is considered here.

For the heat treating cycle described, estimated are three hours of labor to load, operate and unload the job. Using an average labor rate of $15/hr (knowing that several people on the shop floor will be involved ranging from lower to higher rate) for the 3 hour duration the direct labor cost equals $45.00. Again, overhead must be added by one of the two previously mentioned methods.

Cost of Gases—Partial Pressure & Quench

The partial pressure gas usage can calculate our consumption and subsequently the cost. First note in Table IV the variation in cost for three different quench gases. Since gas usage in this case is nitrogen for both the partial pressure and quench, cost for total consumption for the cycle is determined as based on cost for nitrogen. The total flow for partial pressure over the 1 1/2 hour heat-up and 1/2 hour soak is equal to:

$0.55/100 scf * 100 scf/hr * 2 hrs = $1.10

Recalling that the quench volume is 300 scf, then the gas cost for quench is:

$0.55/100 scf * 300 scf = $1.65

The total cost for gas then becomes $2.75. Noting the price comparisons for various gases in Table IV, one can see that argon would be six times as expensive, and helium (for the quench portion) would be 40 times as expensive.

Table IV Cost of Various Quenching Gases

Nitrogen	$0.55/100 scf
Argon	3.00
Helium	20.00

Cost for Fixturing: Grids & Baskets

Fixturing costs must be included also. They include those for the baskets and grids used and any special set up required to process the work. Depending upon material and design, baskets and grids for this furnace can range from $5,000 to $20,000.

Table V Some Items Requiring Maintenance and Their Costs

Pump Oils	$200-1300/55 gallons
Graphite nozzles	5 each
Graphite load rails	200 each
Heating element patch	150 each
Hot face graphite foil	100 per 2' x 3' sheet
Thermocouples-type S	200-300 each
type K	1 per foot
Pump exhaust filters	200-400 per system
Degreasing solvent	300 per 55 gallons
Waste oil & solvent removal	225 per 55 gallons

Dependent on the required life in useful hours, the more expensive alloys will typically prove to be the most economical. Knowing that the average life is five years, this cost is spread out over 5 years. Using the same methods as shown earlier in the furnace cost calculations, determined is a cost range of $0.25 to $0.95 per hour. Additional fixtures that are job specific can be charges to the specific job or amortized if usable again on another project.

Cooling Water Cost

Cooling water is necessary for a vacuum furnace or any "cold walled" vessel. To capture these costs in terms of the hourly rate of the furnace, examined is the expense of the system ($30,000) and this cost is spread over all of the plant equipment for which it is used. With an initial cost of $30,000, a usable life of seven years and treatment and maintenance costs of $12,000/yr one can apply the formula used previously to obtain resultant cost of $3.25/hr. Because the cooling water system handles all the plant equipment, some form of weighting must be used to arrive at a cost per furnace.

Maintenance Costs

Examples of some of the maintenance items often expensed including their approximate costs are listed in Table V.

Hot Zone Replacement Cost

The heating region of the furnace, hot zones, can be expected to last about four years in typical service if maintained. If the new hot zone costs $75,000, its cost per hour can be calculated similarly as done previously. The resultant cost is $4.15/hr.

Totals

Having identified all of the costs for the 4-hour cycle they can be listed and totaled as shown in Table VI. Note that no overhead is included in the labor cost

Table VI Total Cost for Vacuum Furnace Heat Treating Cycle

Furnace ($12.65/hr * 4 hrs)	$50.60
Electric: Heat-up	27.00
soak (hold)	5.65
quench (cool)	15.00
misc.	19.00
Direct Labor	45.00
Process gas	2.75
Fixtures, baskets, grids	3.50
Water system	1.00
Hot zone ($4.15/hr * 4 hrs)	16.60
TOTAL	$186.10

and no routine maintenance costs are included. These figures of course vary with the specific case and can be readily added for the individual application.

Reducing Costs

There are ways in which costs can be reduced so as to increase profits and/or be more competitive in the marketplace. Following are just a few practical ideas:

(1) Standardize furnace parts and equipment as much as possible so that the minimum number of spare parts are required in inventory. This also will increase bulk buying power.

(2) Size fixtures to be used in multiple furnaces to get the most use for them. Doing so will allow a quicker payoff.

(3) Keep stock only of spare parts used regularly or with long lead times to keep inventory low.

(4) Operate large electric power consuming runs at off-peak electric demand times whenever possible to reduce demand spikes.

Summary

All of the above examples are based on financing 100% of the equipment—vacuum furnace; fixtures, baskets and grids; hot zones, etc. If the above components are purchased from retained earnings, then the costs are based not on financing but rather depreciation, typically straight line. The evaluation then becomes, what is the trade off of purchasing from retained earnings versus financing and investing the cash in a higher yield investment. The answer to this question is best left to the accountant. IH