# Aluminum De-Ox Holder Furnace

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
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Bachelor of Science

in Mechanical Engineering Technology

by

Mitchell Fisher and Nick Carnevale

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Thesis Advisor:

**Professor Moise Cummings**

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## ABSTRACT

Al-Rec LLC is an aluminum recycling facility located in Ravenswood, Wv. Previously Al-Rec took scrap and dross aluminum and melted it down and casted it into “T-bars” and ingots to either sell or return to the customer for a fee. Al-Rec’s process used some of the largest rotary furnaces in the world to complete this process in the most efficient manner possible. Al-Rec’s newest product that they wanted to produce were aluminum de-ox cones to sell to the steel and iron industry. To produce this product Al-Rec needed an aluminum holder furnace to hold a supply of aluminum which flowed into an adjacent casting machine. This holder allowed a continuous flow of aluminum into the caster while the rotary furnaces melt a new batch of aluminum. Al-Rec has procured a used furnace frame which will be used as the foundation of this construction project. With the help of Tri-Sate Industrial Services we turned this furnace frame into a working furnace with the scope of work focusing on but not limited to refractory construction.

## PROBLEM DEFINITION AND RESEARCH

### *PROBLEM STATEMENT*

To create an aluminum de-ox holder furnace that will allow an aluminum recycling facility to temporarily hold molten aluminum while giving them a long-lasting refractory design that also allows flexibility.

### *BACKGROUND*

Refractory brick lined furnaces deteriorate quickly due to the quantity of joints, corrosion, erosion, mechanical stress, as well as contact with industrial equipment and temperature cycling. This deterioration will cause a furnace to fail and will need to be rebuilt. This will cause extended downtime in the factory as well as high costs to rebuild the furnace. There are many different current solutions to extend the life of refractory in a furnace depending on the application. This can include using brick vs castable refractory, or even fiber. These all depend on the type of furnace, duty cycles, maximum temperature, and what material is being melted or heated. During the summer of 2018 Mitch Fisher worked at the refractory construction company Tri-State Industrial Services Inc. We are pursuing this project to apply principles learned over that period to design a highly efficient furnace that can withstand specific application requirements. Today furnaces are being rebuilt with various refractory and construction techniques due to application requirements, pricing limitations, time constraints, as well as supplier, contractor and owner preferences.

## RESEARCH

### *SCOPE OF THE PROBLEM*

Al-Rec is an aluminum recycler that currently has the capacity to melt scrap and dross aluminum and cast it into “T-Bars.” Al-Rec is looking to expand its product line into De-Ox Aluminum cones. To produce this product, Al-Rec needs a “holder furnace” that can hold molten aluminum while rotary furnaces cycle. This will allow a constant flow aluminum into a casting machine. This furnace will need to be able to withstand metal contact, thermal cycling, chemical attack, resist abrasion, and allow efficient loading and maintenance.

### *CURRENT STATE OF THE ART*

Today there are multiple categories of products that are used as heat insulation in industrial furnace applications. They each have pros and cons due to the specific applications. Refractory brick is often used in areas where there is metal contact and there are heat cycles due to downtime. Brick is widely available and highly consistent. It is very easy to replace certain areas of damaged furnaces when it is built with brick rather than monolithic material. Fiber is used in non-contact applications where there are no mechanical stresses. This is often for reheat furnaces for forging applications. Fiber can be fabricated into multiple different forms whether it be paper, blanket or modules. Fiber is relatively cheap and can have very favorable insulation characteristics but may not have a long lifespan and could require high upfront installation labor costs.

Pre-cast refractory can be very efficient and allows a specific shape to be cast where it is easy to keep manufacturing quality controls in place to ensure high quality castings. These shapes can then be placed in the field without the need for long on-site installations and high labor costs.

Shotcrete/Gunite is done by pumping material through a hose and having it sprayed or shot onto a surface. This allows you to create a rough shape of layer that you can then refine by hand. It can be used to shoot walls, ceilings, floors and other areas of the furnace without the need for forming and can also create a monolithic design without joints.

Colloidal Silica vs. Cement Bond – Most refractories use Calcium Aluminate Cement (CAC) as the bonding material for refractory aggregate. This CAC is combined with water which will activate the bonding. During different stages of heating this water is driven off in two phases. First the physically bonded water then the chemically bonded water. Due to this process the bonding strength will decrease including other characteristics that will lead to the failure of the product.  Colloidal Silica bonded refractory uses has no chemically bonded water or CAC. This product uses a colloidal silica binder that is mixed with the dry aggregate. Because there is no chemically bonded water the material will have much higher performance at high temperatures. (Magneco Metrel, 2001)

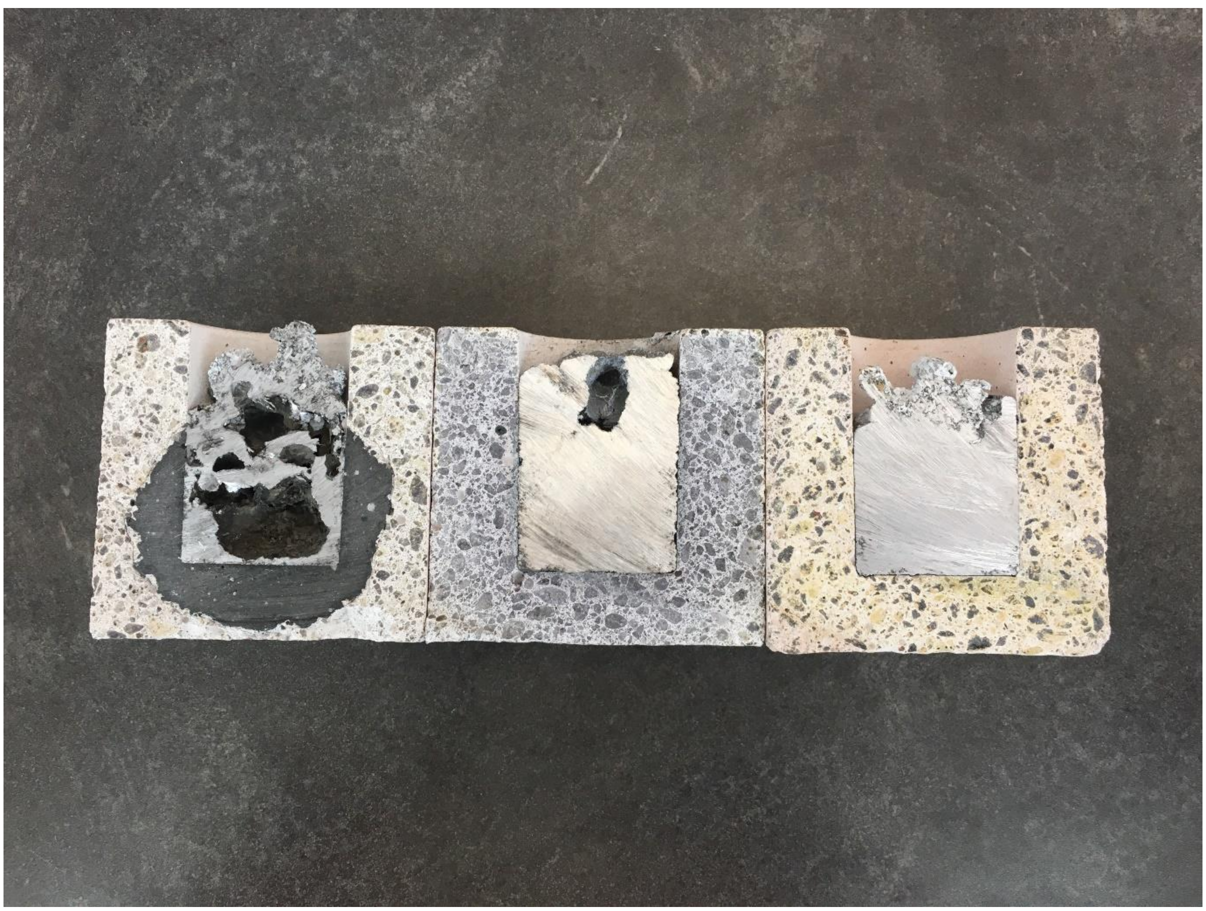

Figure 1: Refractory testing. Left to right: Cement, IPSX, ASX-60 Al-MG

***END USER***

The end user for this project will be Al-Rec LLC which is an aluminum recycling facility in Ravenswood, Wv. This facility wants a furnace that can withstand their specific application. The longer that this furnace can last the longer they will be in production and the less they spend on maintenance and repair or rebuild costs. The uniqueness of this project will come from their custom application. Because these are industrial applications there are many variables that are difficult to control or eliminate. This means that each rebuild, and each furnace is different.

***CONCLUSIONS AND SUMMARY OF RESEARCH***

All metal contact refractory solutions that involve quick thermal cycling require high quality, long lasting solutions. The only material that can handle this type application is Magneco Metrel's line of Met-Pump refractory.

## CUSTOMER FEATURES

**Customer Features**

Durable
Cost effective
Heat efficient
Thermal cyclability
Ease of maintenance
Safe
Life Span

**Engineering Characteristics**

Material cost
Labor cost
Abrasion resistance
Chemical resistance
Hot strength
Heat conductivity
Modularity

**House of Quality**

| | | | Engineering Requirements (units) | | | | | | | | | | | | | | Customer Satisfaction Rating (0.00 - 1.00) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Importance wt. | MATERIAL COST | LABOR COST | ABRASION RESISTANCE | CHEMICAL RESISTANCE | HOT STRENGTH | LINEAR CHANGE | HEAT CONDUCTIVITY | MODULARITY | | | | | | | | | | |
| | Customer Requirements | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | CP | A | B | C |
| 1 | DURABLE | 0.20 | 3 | 1 | 8 | 8 | 8 | 8 | 1 | 3 | | | | | | | 0.8 | 0.8 | 0.6 | 0.4 |
| 2 | COST EFFECTIVE | 0.20 | 9 | 9 | 1 | 1 | 1 | 1 | 1 | 3 | | | | | | | 0.9 | 0.2 | 0.8 | 0.8 |
| 3 | HEAT EFFICIENT | 0.05 | 1 | 1 | 3 | 1 | 1 | 1 | 9 | 3 | | | | | | | 0.7 | 0.5 | 0.5 | 0.6 |
| 4 | THERMAL CYCLABILITY | 0.05 | 9 | 1 | 1 | 1 | 5 | 8 | 3 | 7 | | | | | | | 0.9 | 0.8 | 0.6 | 0.9 |
| 5 | EASE OF MAINTENANCE | 0.10 | 8 | 9 | 5 | 5 | 1 | 3 | 1 | 9 | | | | | | | 0.9 | 0.3 | 0.3 | 0.9 |
| 6 | SAFE | 0.20 | 1 | 7 | 3 | 3 | 3 | 3 | 3 | 3 | | | | | | | 0.7 | 0.7 | 0.7 | 0.7 |
| 7 | LIFE SPAN | 0.20 | 9 | 9 | 9 | 9 | 9 | 9 | 3 | 9 | | | | | | | 0.4 | 0.8 | 0.6 | 0.4 |
| 8 | | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | | |
| | Total Importance | 1.00 | | | | | | | | | | | | | | | | | | |
| | Engineering requirement importance | | 5.7 | 6.2 | 4.9 | 4.8 | 4.6 | 4.95 | 2.3 | 5 | | | | | | | | | | |
| **Performance** | Current Product | | 7 | 3 | 4 | 5 | 6 | 1 | 2 | 8 | | | | | | | | | | |
| | competitor A | | 1 | 6 | 7 | 5 | 8 | 4 | 2 | 3 | | | | | | | | | | |
| | competitor B | | 4 | 3 | 7 | 8 | 6 | 5 | 1 | 2 | | | | | | | | | | |
| | competitor C | | 8 | 2 | 3 | 4 | 5 | 1 | 6 | 7 | | | | | | | | | | |
| | New Product Targets | | 4 | 3 | 7 | 6 | 8 | 5 | 1 | 2 | | | | | | | | | | |

**Interaction Matrix**

| 9,3,1, -9,-3,-1 | Engineering Requirements | MATERIAL COST | LABOR COST | ABRASION RESISTANCE | CHEMICAL RESISTANCE | HOT STRENGTH | LINEAR CHANGE | HEAT CONDUCTIVITY | MODULARITY | 0 | 0 | 0 | 0 | 0 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Engineering Requirements** | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| MATERIAL COST | 1 | | 3 | -9 | 1 | 1 | 1 | 1 | -3 | | | | | | |
| LABOR COST | 2 | | | -9 | 9 | 9 | 9 | 9 | 3 | | | | | | |
| ABRASION RESISTANCE | 3 | | | | 9 | -3 | 1 | 1 | 3 | | | | | | |
| CHEMICAL RESISTANCE | 4 | | | | | 9 | 9 | 9 | 3 | | | | | | |
| HOT STRENGTH | 5 | | | | | | 3 | 9 | 3 | | | | | | |
| LINEAR CHANGE | 6 | | | | | | | 9 | 3 | | | | | | |
| HEAT CONDUCTIVITY | 7 | | | | | | | | 3 | | | | | | |
| MODULARITY | 8 | | | | | | | | | | | | | | |
| 0 | 9 | | | | | | | | | | | | | | |
| 0 | 10 | | | | | | | | | | | | | | |
| 0 | 11 | | | | | | | | | | | | | | |
| 0 | 12 | | | | | | | | | | | | | | |
| 0 | 13 | | | | | | | | | | | | | | |
| 0 | 14 | | | | | | | | | | | | | | |

Figure 2: House of quality

## PRODUCT OBJECTIVES

Customer Features

| Rank | Feature | Survey Result |
|---|---|---|
| 1 | WORKER SAFETY | 5 |
| 2 | SERVICE LIFE | 4.6 |
| 3 | EASE OF MAINTENANCE | 4.4 |
| 4 | DURABILITY - LOADING/UNLOADING | 4.3 |
| 5 | INITIAL INVESTMENT COST | 4.1 |
| 6 | THERMAL CYCLABILITY | 4 |
| 7 | CONSTRUCTION TIME | 3.7 |
| 8 | HEAT INSULATION | 3.5 |
| 9 | START UP TIME | 3.3 |

Figure 3: Customer features

Worker safety
- Construction methods use appropriate safety standards
- OSHA
- Wall/Ceiling anchor is appropriately spaced
- Combustion
- Loading/unloading ease
- Furnace load support

Service life
- How long will material last
- Partial reconstruction intervals
- Loading/unloading procedures
- Cause of failure?

Ease of maintenance
- Brick vs. monolithic
- Jambs, lintel, sill replacement
- Dross removal

Durability
- Do operators load with heavy equipment ie. forklift
- Does metal fall into well from trough
- Flue exhaust velocity?
- Thermal cycling?

Initial Investment
- Material cost
- Labor cost
- Construction time
- Start-up

- Opportunity cost

Thermal Cyclability

- How often does furnace shut-down
- Do metal levels rise and fall throughout operation
- Burner orientation

Construction Time

- Demolition
- Shift length
- Man power
- Parts, equipment, material secured
- Backup parts, equipment?
- Leadership
- Construction methods

Heat insulation

- Thickness of material
- Backup material ie. Cal-Sil Block
- Effect on load support ie. anchor c clip
- Energy costs

Start-up time

- Opportunity cost
- Refractory dry out
- Ownership of dry out

# QUALITY FUNCTION DEPLOYMENT

| | Customer Requirements | Importance wt. | 1 MATERIAL COST | 2 LABOR COST | 3 ABRASION RESISTANCE | 4 CHEMICAL RESISTANCE | 5 HOT STRENGTH | 6 LINEAR CHANGE | 7 HEAT CONDUCTIVITY | 8 MODULARITY | 9 | 10 | 11 | 12 | 13 | 14 | CP | A | B | C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Engineering Requirements** (units) | | | | | | | | | | | | | | **Customer Satisfaction Rating** (0.00 - 1.00) | | | |
| 1 | DURABLE | 0.20 | 3 | 1 | 8 | 8 | 8 | 8 | 1 | 3 | | | | | | | 0.8 | 0.8 | 0.6 | 0.4 |
| 2 | COST EFFECTIVE | 0.20 | 9 | 9 | 1 | 1 | 1 | 1 | 1 | 3 | | | | | | | 0.9 | 0.2 | 0.8 | 0.8 |
| 3 | HEAT EFFICIENT | 0.05 | 1 | 1 | 3 | 1 | 1 | 1 | 9 | 3 | | | | | | | 0.7 | 0.5 | 0.5 | 0.6 |
| 4 | THERMAL CYCLABILITY | 0.05 | 9 | 1 | 1 | 1 | 5 | 8 | 3 | 7 | | | | | | | 0.9 | 0.8 | 0.6 | 0.9 |
| 5 | EASE OF MAINTENANCE | 0.10 | 8 | 9 | 5 | 5 | 1 | 3 | 1 | 9 | | | | | | | 0.9 | 0.3 | 0.3 | 0.9 |
| 6 | SAFE | 0.20 | 1 | 7 | 3 | 3 | 3 | 3 | 3 | 3 | | | | | | | 0.7 | 0.7 | 0.7 | 0.7 |
| 7 | LIFE SPAN | 0.20 | 9 | 9 | 9 | 9 | 9 | 9 | 3 | 9 | | | | | | | 0.4 | 0.8 | 0.6 | 0.4 |
| 8 | | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | | |
| | Total Importance | 1.00 | | | | | | | | | | | | | | | | | | |
| | Engineering requirement importance | | 5.7 | 6.2 | 4.9 | 4.8 | 4.6 | 4.95 | 2.3 | 5 | | | | | | | | | | |

| Performance | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Current Product | 7 | 3 | 4 | 5 | 6 | 1 | 2 | 8 | | | | | | |
| | competitor A | 1 | 6 | 7 | 5 | 8 | 4 | 2 | 3 | | | | | | |
| | competitor B | 4 | 3 | 7 | 8 | 6 | 5 | 1 | 2 | | | | | | |
| | competitor C | 8 | 2 | 3 | 4 | 5 | 1 | 6 | 7 | | | | | | |
| | New Product Targets | 4 | 3 | 7 | 6 | 8 | 5 | 1 | 2 | | | | | | |

**Interaction Matrix**

| **9,3,1, -9,-3,-1** <br> **Engineering Requirements** | **Engineering Requirements** | 1 MATERIAL COST | 2 LABOR COST | 3 ABRASION RESISTANCE | 4 CHEMICAL RESISTANCE | 5 HOT STRENGTH | 6 LINEAR CHANGE | 7 HEAT CONDUCTIVITY | 8 MODULARITY | 9 0 | 10 0 | 11 0 | 12 0 | 13 0 | 14 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MATERIAL COST | 1 | | 3 | -9 | 1 | 1 | 1 | 1 | -3 | | | | | | |
| LABOR COST | 2 | | | -9 | 9 | 9 | 9 | 9 | 3 | | | | | | |
| ABRASION RESISTANCE | 3 | | | | 9 | -3 | 1 | 1 | 3 | | | | | | |
| CHEMICAL RESISTANCE | 4 | | | | | 9 | 9 | 9 | 3 | | | | | | |
| HOT STRENGTH | 5 | | | | | | 3 | 9 | 3 | | | | | | |
| LINEAR CHANGE | 6 | | | | | | | 9 | 3 | | | | | | |
| HEAT CONDUCTIVITY | 7 | | | | | | | | 3 | | | | | | |
| MODULARITY | 8 | | | | | | | | | | | | | | |
| 0 | 9 | | | | | | | | | | | | | | |
| 0 | 10 | | | | | | | | | | | | | | |
| 0 | 11 | | | | | | | | | | | | | | |
| 0 | 12 | | | | | | | | | | | | | | |
| 0 | 13 | | | | | | | | | | | | | | |
| 0 | 14 | | | | | | | | | | | | | | |

Figure 4: House of quality

## DESIGN

Design alternatives and selection

Example of furnace layout and material configuration

| LINING CONFIGURATION | | | |
|---|---|---|---|
| SECTION | TOTAL THICKNESS | MATERIAL | MATERIAL THICKNESS |
| HEARTH | 21.5" | MATRICAST 2500AC | 8" |
| | | MATRIPUMP 72 ACX | 13.5" |
| LOWER WALLS | 18" | DURABLOCK 1900 BOARD | 1.5" |
| | | MATRILITE 24 AC G | 3" |
| | | MATRIPUMP 72 ACX | 13.5" |
| UPPER WALLS | 18" | DURABLOCK 1900 BOARD | 6" |
| | | MATRIPUMP AR61 | 12" |
| ROOF | 12" | MATRIPUMP 50 | 9" |
| | | INSULMIX 20 | 3" |
| LINTEL | 15" | MATRIPUMP AR61 | 12" |
| | | INSULMIX 20 | 3" |
| SILL | 12X12 | MATRIPUMP 63 CX | PRE-CAST |
| JAMBS | 12X12 | MATRIPUMP AR 61 | PRE-CAST |
| FLUE | 9" | MATRIPUMP 50 | 7.5" |
| | | INSULBLOCK | 1.5" |

Figure 5: Proposed refractory layout

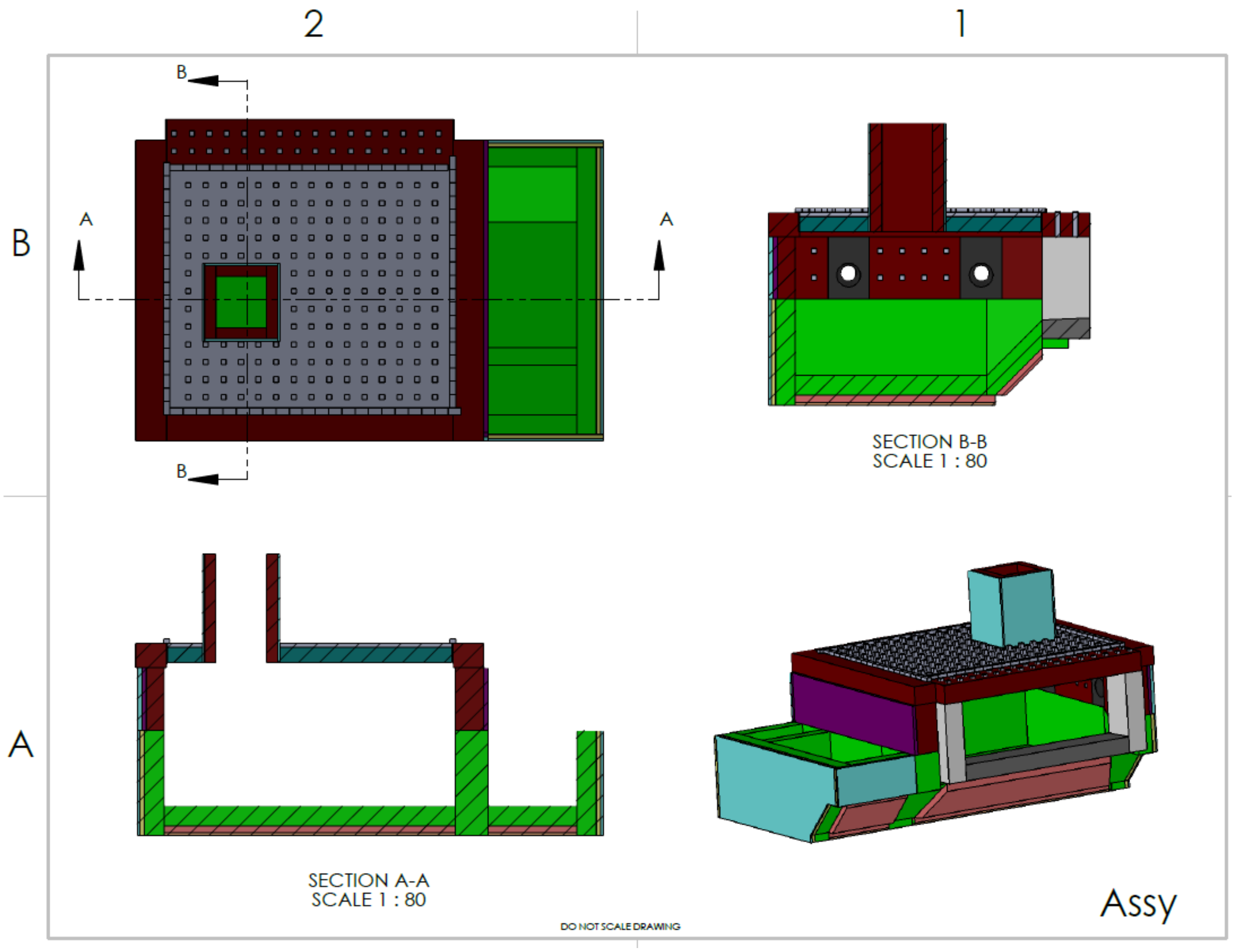


Figure 6: Current refractory layout drawing example

Concept #1

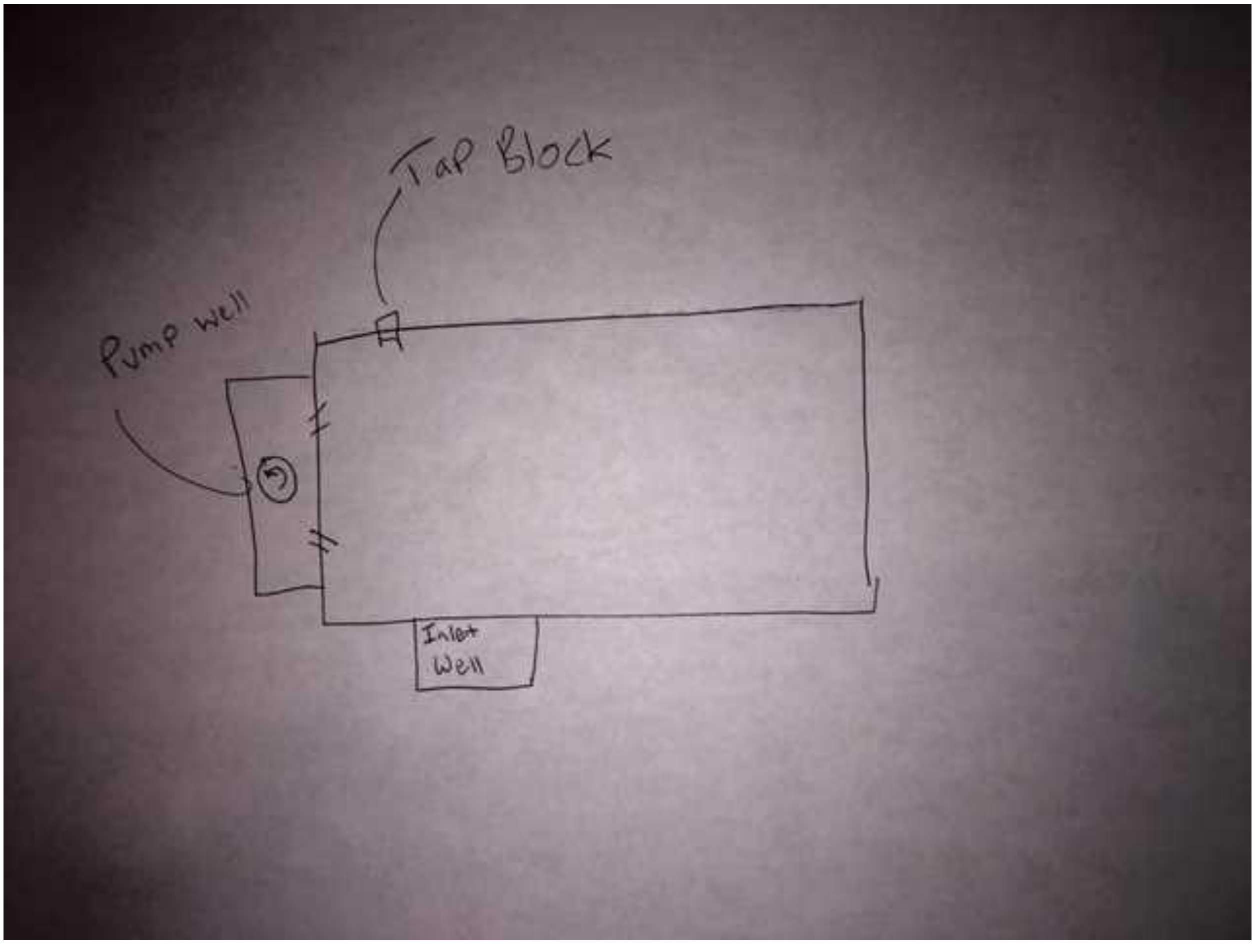


Figure 7: Concept 1

Concept #2

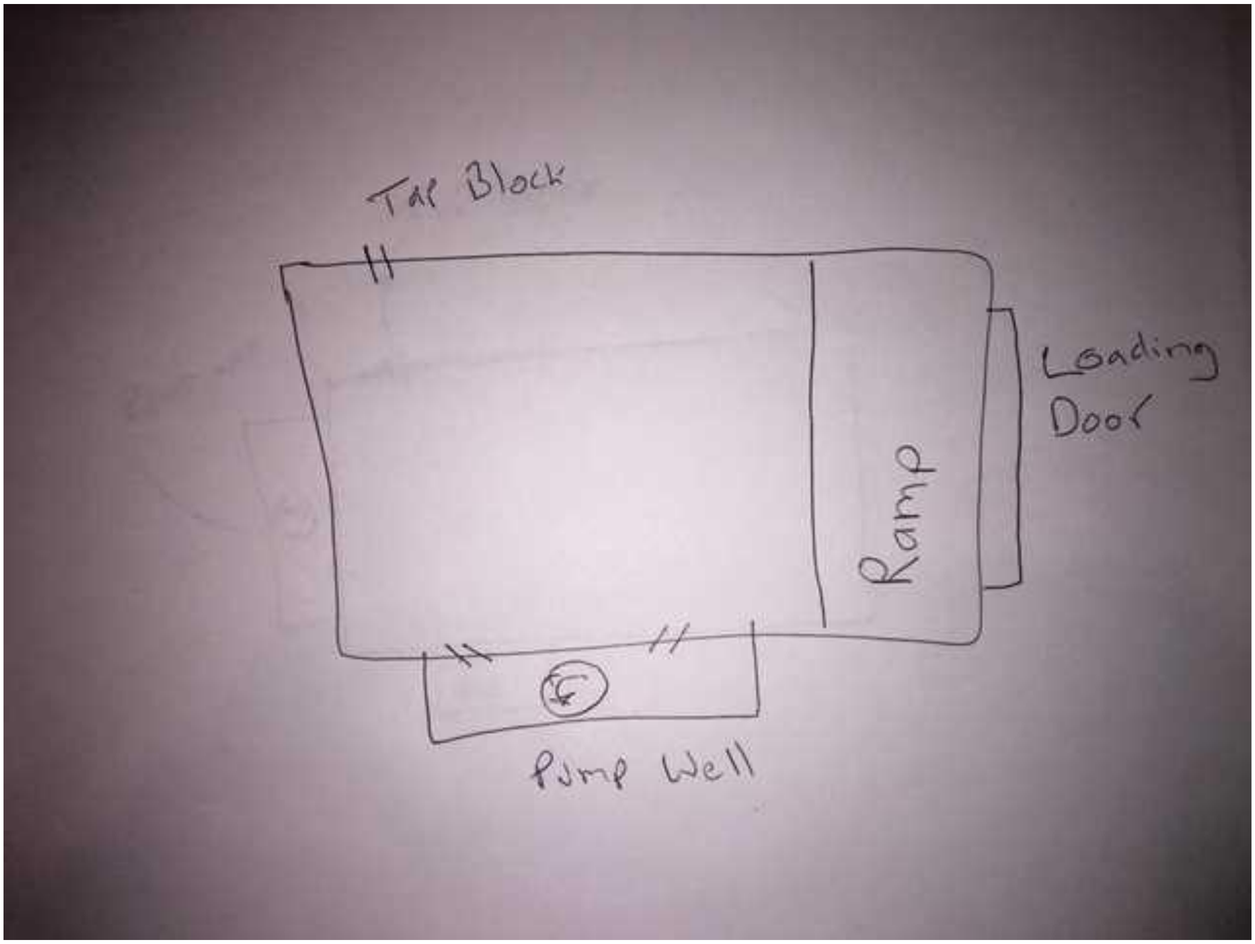


Figure 8: Concept 2

Concept #3

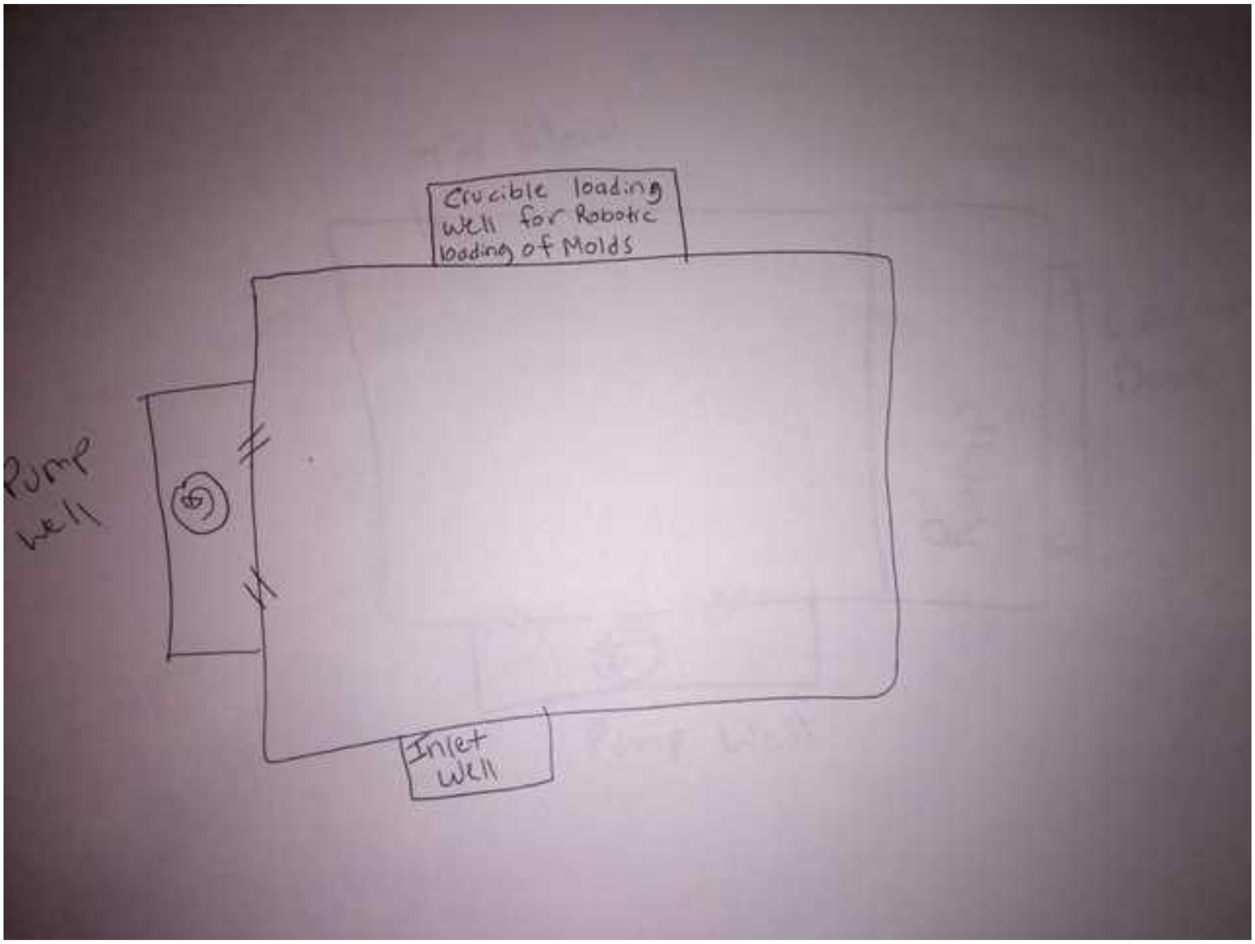


Figure 9: Concept 3

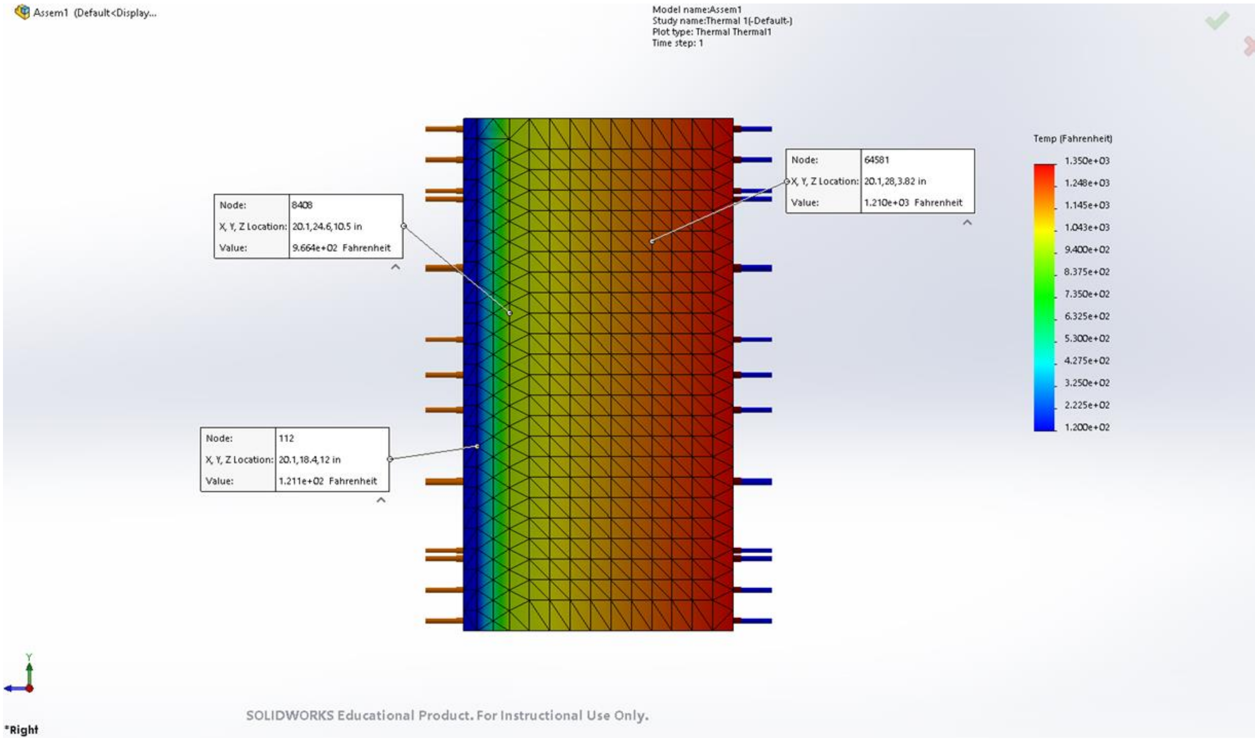

Figure 10: Lower wall refractory heat calculation

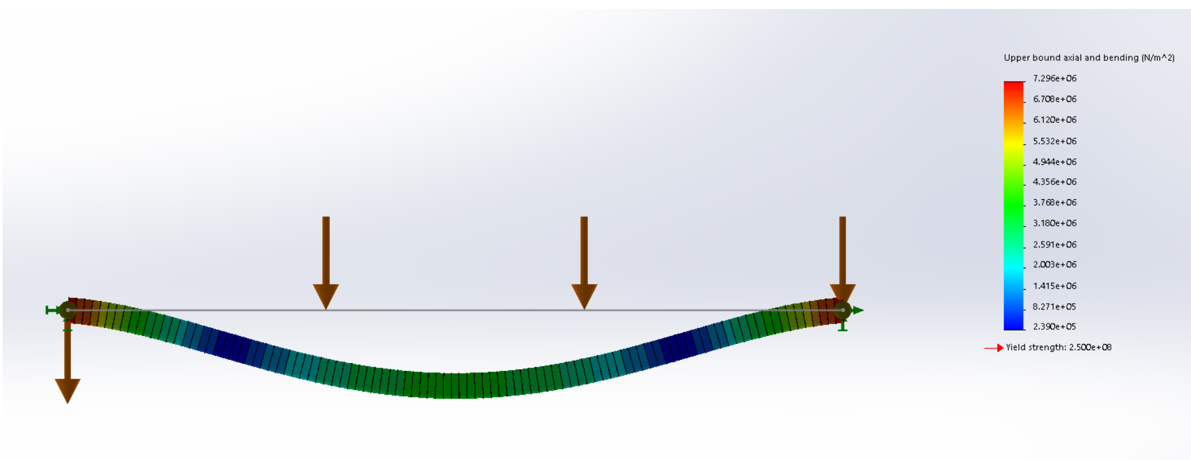


Figure 11: Roof large gauge I-beam load calculation

### Suggested Spacing for Ceramic Refractory Anchors

| Locations | Lining Thickness (In.) | Anchoring Spacing (in.) |
|---|---|---|
| Vertical and circular units | 9-12<br>12-15<br>15+ | 15<br>18<br>24 |
| Roofs, noses and arches | 6+ | 12 |

**Harbison-Walker IR - 69**

Figure 12: Industry standard anchor layout recommendation

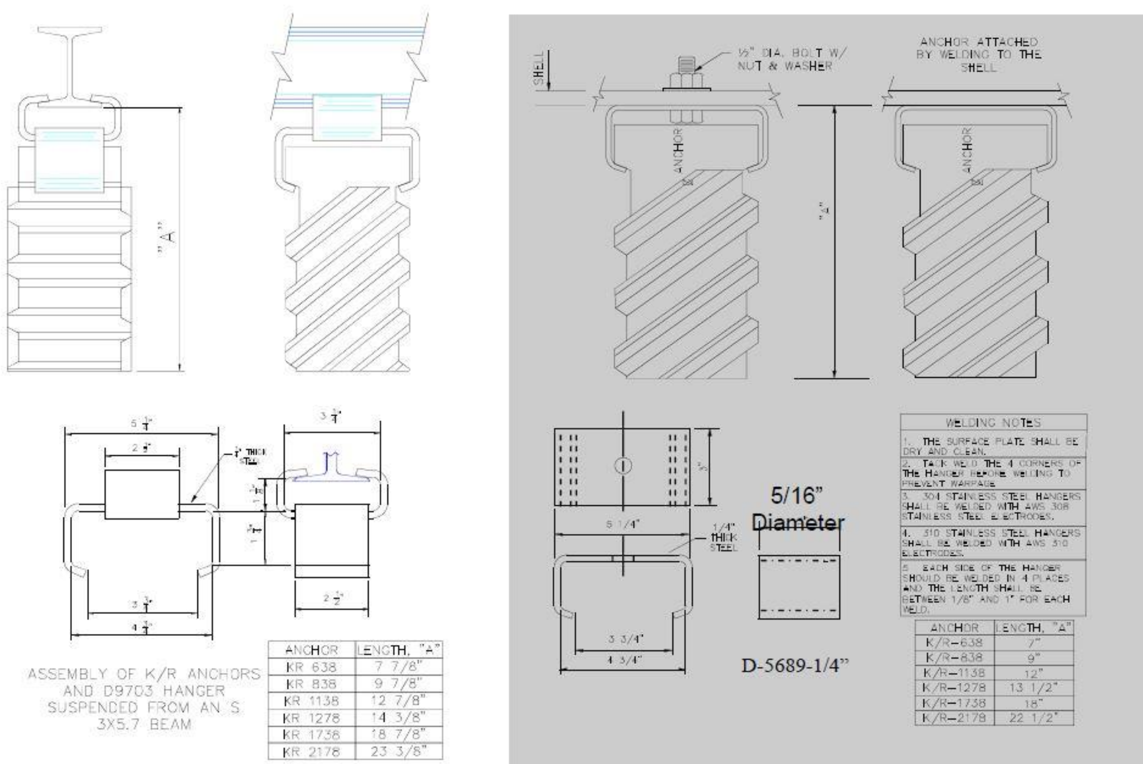


Figure 13: Common anchor brick design

| | | |
|---|---|---|
| • Sub hearthback-up | Cal-Sil Block | 1.5” |
| • Working Hearth | Metpump ASX 60 AL Mg | 10.5” |
| • Lower Walls | Cal-Sil Block | 1.5” |
| | Metpump ASX 60 AL MG | 10.5” |
| • Upper Walls | Mineral Wool Block | 1.5” |
| | 2300 F Insulation Brick | 3” |
| | Metpump ASX 60 AL MG SC | 7.5” |
| • Roof | Metpump ASX 40 AL MG | 8” |
| | Light Weight Cast | 3” |

Lintel: 12”x12” ASX 60 Jambs: Allied Quickcast 61 ACX

Sill: C-180

Figure 14: Proposed refractory design

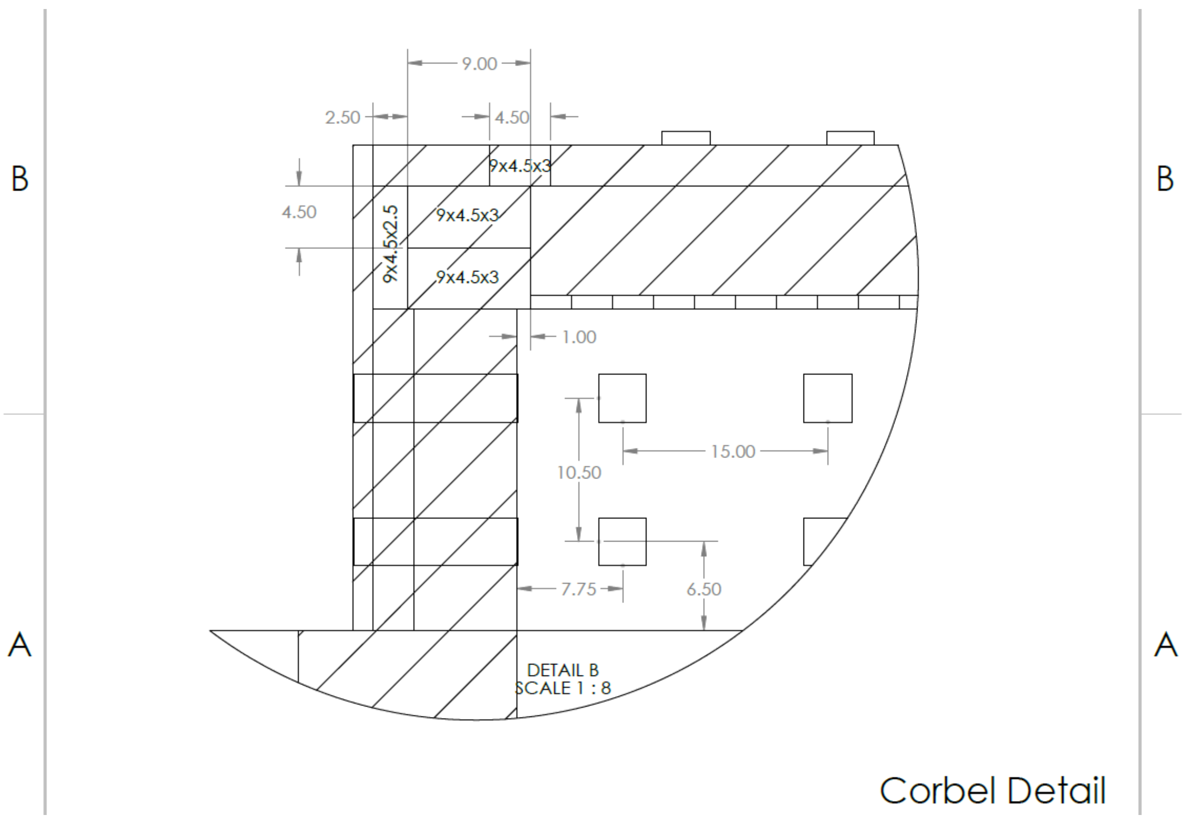


Figure 15: Proposed corbel design

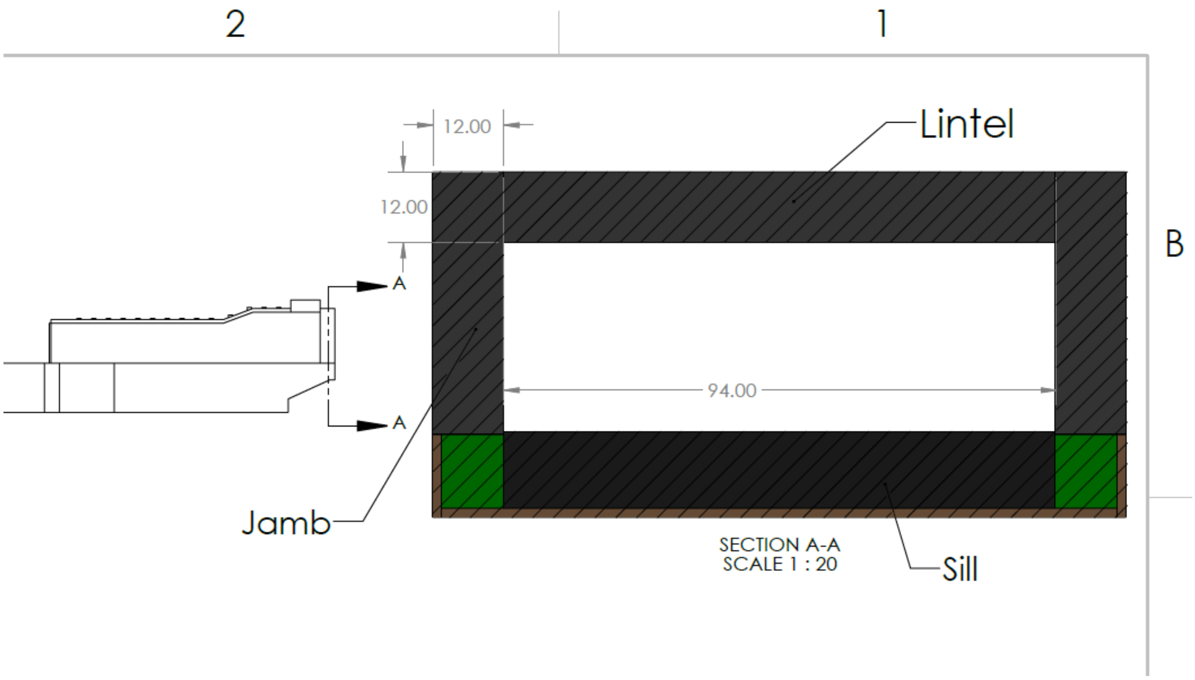


Figure 16: Proposed lintel, jamb and sill design

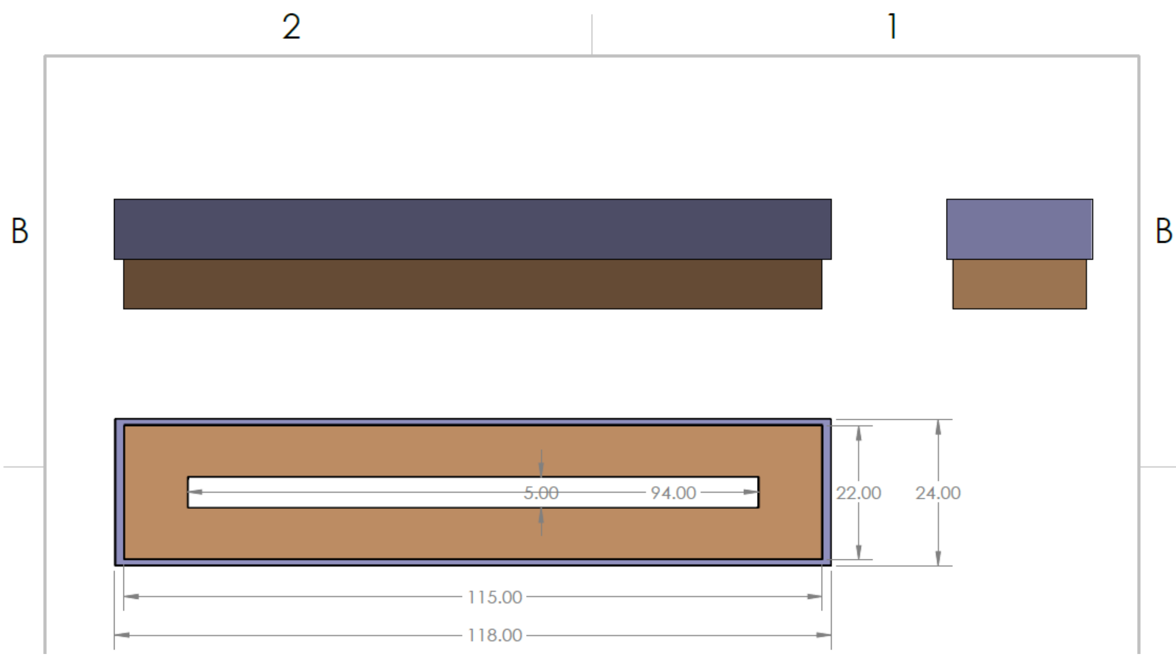


Figure 17: Proposed flue design

| | | | | | |
|---|---|---|---|---|---|
| | **MATERIAL ESTIMATE** | | | | |
| CUST: | | | | DATE: | 12/3/2018 |
| LOC: | | | | PROPOSAL NO: | |
| JOB- | | | | JOB NO: | |
| DESCRIP: | 30,000# Holder | | | SHEET NO: | OF |
| | | QUANTITY | | COST | |
| MTLCODE | DESCRIPTION | NET | GROSS | UNIT | EXTEND. |
| | **Material** | | | | |
| 202 | Metpump ASX 60 AL MG | | 58,500 | $ 0.61 | $ 35,685.00 |
| 202 | Metpump ASX 60 AL MG (Well) | | | $ 0.61 | $ 0.61 |
| 202 | Metpump ASX 60 AL MG SC (U.W) | | 12,000 | $ 0.62 | $ 7,440.00 |
| 202 | Metpump ASX 40 AL MG(Roof & Flue) | | 18,000 | $ 0.54 | $ 9,720.00 |
| 202 | LW 35 G (Roof) | | 2,000 | $ 0.65 | $ 1,300.00 |
| 202 | Metpump C-180 AL MG (Sill) | | 2,000 | $ 0.70 | $ 1,400.00 |
| 202 | QuickCast 61 ACX (Jambs & Lentil) | | 3,000 | $ 0.58 | $ 1,740.00 |
| 201 | 2300 IFB 9 x 4.5 x 3" (U.W.) | | 550 | $ 2.75 | $ 1,512.50 |
| 201 | Super Duty 13.5 x 4.5 x 3" Str. (Roof Seal) | | 450 | $ 5.50 | $ 2,475.00 |
| | | | | 0 | $ - |
| | **Anchors** | | | | |
| 201 | 16" Brick Anchors (S.W.) | | 80 | $ 23.20 | $ 1,856.00 |
| 201 | 12" Brick Anchors (Roof) | | 165 | $ 17.50 | $ 2,887.50 |
| 221 | 304 SS Beam Hanges (C-Clips) | | 165 | $ 7.50 | $ 1,237.50 |
| 221 | 304 SS Wall C-Clips | | 80 | $ 4.25 | $ 340.00 |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | **Board, Blanket, Paper (per Sq. Ft.)** | | | | |
| 206 | Skamol 1100 E Super 1.5" | | 540 | $ 3.500 | $ 1,890.00 |
| 206 | Durablock 1900 1.5" | | 100 | $ 2.500 | $ 250.00 |
| 206 | | | 50 | $ 2.000 | $ 100.00 |
| 206 | Ceramic Fiber Blkt - 1" - 2600 | | 100 | $ 1.500 | $ 150.00 |
| | **Brick/Other (Manual Input)** | | | | |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | TOTAL COST.......... | | $ 69,984.11 |
| | | | FREIGHT................ | | |

Figure 18: Material summary

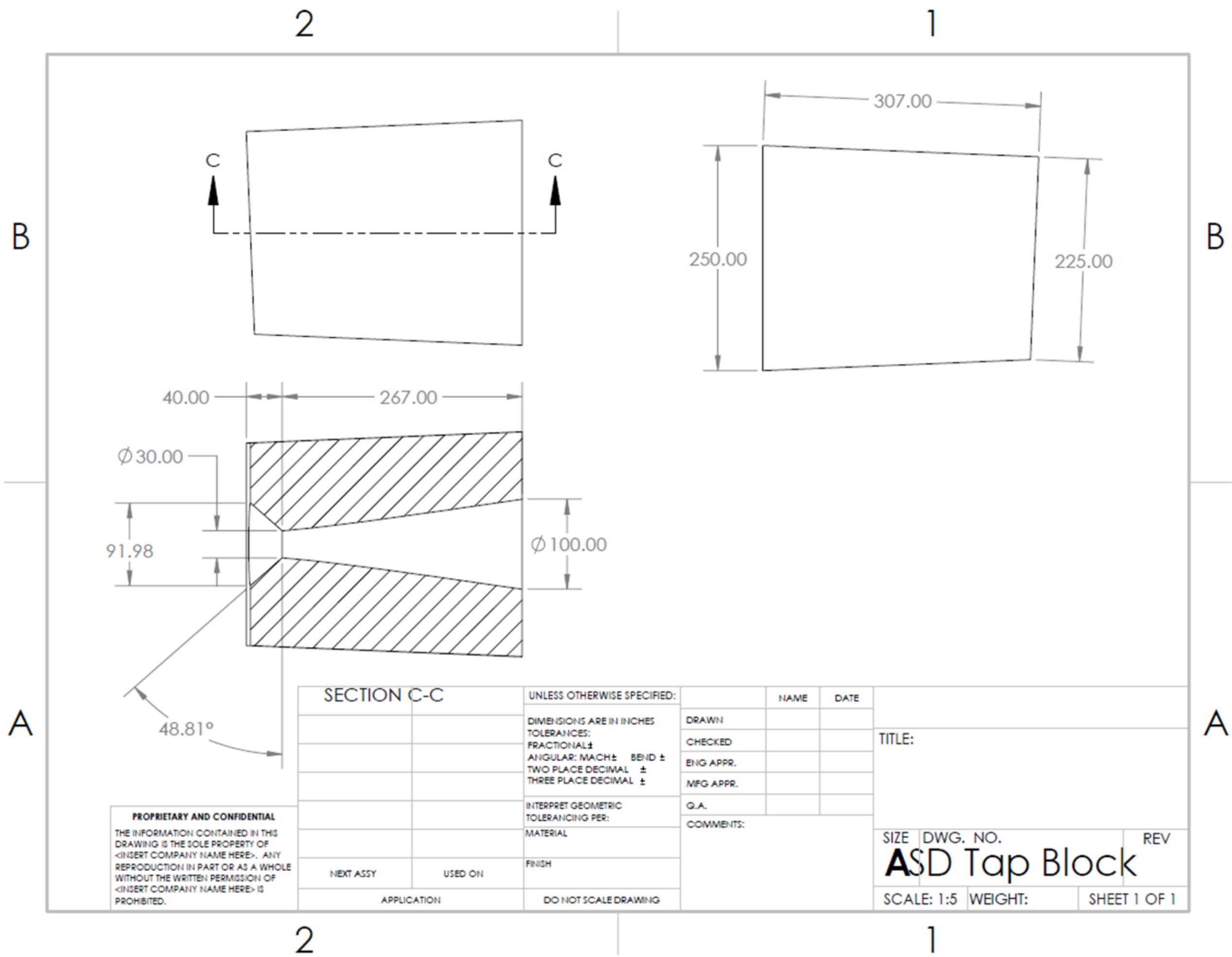


Figure 19: Tap Block Design

# PROJECT MANAGEMENT

## *BUDGET, PROPOSED/ACTUAL*

**JOB RECAP SHEET**

| | | | |
|---|---|---|---|
| **CUST:** | | **DATE:** | 12/3/2018 |
| **LOC:** | | **PROPOSAL NO:** | |
| **JOB-** | | Created BY: | MGF |
| **DESCRIPTION:** | 30,000# Holder | **JOB NO:** | |

**JOB RECAP :**

| | COST LEVEL | Selling Price | |
|---|---|---|---|
| **MATERIALS.........................................** | $ | $ 88,529.90 | |
| **DIRECT LABOR.....................................** | $ | $ 72,995.81 | |
| **SUB,MOBILIZATION,&MILEAGE.............** | $ | $ 19,741.13 | |
| **EQUIP,RENTALS, &CONSUMABLES........** | $ | $ 17,847.76 | |
| **SUB-CONTACTORS................................** | $ | $ 11,403.98 | |
| **FREIGHT...............................** | $ | $ - | |
| **TOTAL BID WITH FREIGHT....................** | $ | $ 210,518.57 | **Price Quoted** |
| **ESTIMATED JOB CONTRIBUTION.......................** | | $ 63,592.74 | |
| **TOTAL JOB MARGIN.........................................** | | 30% | |

Figure 20: Budget summary

| | | | | | |
|---|---|---|---|---|---|
| **MATERIAL ESTIMATE** | | | | | |
| CUST: | | | | DATE: | 12/3/2018 |
| LOC: | | | | PROPOSAL NO: | |
| JOB- | | | | JOB NO: | |
| DESCRIP: 30,000# Holder | | | | SHEET NO: | OF |
| | | QUANTITY | | COST | |
| MTLCODE | DESCRIPTION | NET | GROSS | UNIT | EXTEND. |
| | | **Material** | | | |
| 202 | Metpump ASX 60 AL MG | | 58,500 | $ 0.61 | $ 35,685.00 |
| 202 | Metpump ASX 60 AL MG (Well) | | | $ 0.61 | $ 0.61 |
| 202 | Metpump ASX 60 AL MG SC (U.W) | | 12,000 | $ 0.62 | $ 7,440.00 |
| 202 | Metpump ASX 40 AL MG(Roof & Flue) | | 18,000 | $ 0.54 | $ 9,720.00 |
| 202 | LW 35 G (Roof) | | 2,000 | $ 0.65 | $ 1,300.00 |
| 202 | Metpump C-180 AL MG (Sill) | | 2,000 | $ 0.70 | $ 1,400.00 |
| 202 | QuickCast 61 ACX (Jambs & Lentil) | | 3,000 | $ 0.58 | $ 1,740.00 |
| 201 | 2300 IFB 9 x 4.5 x 3" (U.W.) | | 550 | $ 2.75 | $ 1,512.50 |
| 201 | Super Duty 13.5 x 4.5 x 3" Str. (Roof Seal) | | 450 | $ 5.50 | $ 2,475.00 |
| | | | | 0 | $ - |
| | | **Anchors** | | | |
| 201 | 16" Brick Anchors (S.W.) | | 80 | $ 23.20 | $ 1,856.00 |
| 201 | 12" Brick Anchors (Roof) | | 165 | $ 17.50 | $ 2,887.50 |
| 221 | 304 SS Beam Hanges (C-Clips) | | 165 | $ 7.50 | $ 1,237.50 |
| 221 | 304 SS Wall C-Clips | | 80 | $ 4.25 | $ 340.00 |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | **Board, Blanket, Paper (per Sq. Ft.)** | | | |
| 206 | Skamol 1100 E Super 1.5" | | 540 | $ 3.500 | $ 1,890.00 |
| 206 | Durablock 1900 1.5" | | 100 | $ 2.500 | $ 250.00 |
| 206 | | | 50 | $ 2.000 | $ 100.00 |
| 206 | Ceramic Fiber Blkt - 1" - 2600 | | 100 | $ 1.500 | $ 150.00 |
| | | **Brick/Other (Manual Input)** | | | |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | | 0 | $ - |
| | | | TOTAL COST.......... | | $ 69,984.11 |
| | | | FREIGHT................ | | |

Figure 21: Material budget

**LABOR ESTIMATE**

CUST.
LOC:
JOB-
DESCRIP: 30,000# Holder

DATE: 12/3/2018
PROPOSAL NO:
JOB NO:
SHEET NO: OF

(Use Either Staffing Sheet or Standard)

| | | | | | | | Standard Method | | | Staffing Sheet | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COST CODE | LABOR CLASS | | MAN HRS. | Rate Lab w/Bur. | Labor Cost | | Weekday | Saturday | Sunday | Man Hours | Rate Lab w/Bur. | Labor Cost |
| | SUPERINTENDENT | | | | | | | | | | | |
| 101 | | STR. | 64 | $ 47.48 | $ 3,039 | # Shifts | 8 | 1 | 1 | | $ 47.48 | $ - |
| 101 | | O.T. | 44 | $ 62.87 | $ 2,766 | # People/Sh | 1 | 1 | 1 | | $ 62.87 | $ - |
| 101 | | DOUBLE | 12 | $ 88.26 | $ 1,059 | Hours/Shift | 12 | 12 | 12 | | $ 88.26 | $ - |
| | FOREMAN | | | | | | | | | | | |
| 101 | | STR. | 160 | $ 34.91 | $ 5,586 | # Shifts | 20 | | | | $ 34.91 | $ - |
| 101 | | O.T. | 60 | $ 49.71 | $ 2,983 | # People/Sh | 1 | | | | $ 49.71 | $ - |
| 101 | | DOUBLE | | $ 64.51 | $ - | Hours/Shift | 11 | | | | $ 64.51 | $ - |
| | SKILLED MECHANIC | | | | | | | | | | | |
| 101 | | STR. | 480 | $ 31.44 | $ 15,091 | # Shifts | 20 | | | | $ 31.44 | $ - |
| 101 | | O.T. | 180 | $ 44.59 | $ 8,026 | # People/Sh | 3 | | | | $ 44.59 | $ - |
| 101 | | DOUBLE | | $ 57.74 | $ - | Hours/Shift | 11 | | | | $ 57.74 | $ - |
| | TENDER | | | | | | | | | | | |
| 101 | | STR. | 160 | $ 25.74 | $ 4,118 | # Shifts | 20 | | | | $ 25.74 | $ - |
| 101 | | O.T. | 60 | $ 36.16 | $ 2,170 | # People/Sh | 1 | | | | $ 36.16 | $ - |
| 101 | | DOUBLE | | $ 46.50 | $ - | Hours/Shift | 11 | | | | $ 46.50 | $ - |
| | TOTAL MAN HOURS............... | | 1220 | | $ 44,838 | | | | | | | $ - |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SUBSISTANCE & TRAVEL: | | | | | | | |
| | Travel Required? | y | | | | | |
| | | | | | | | |
| | | 120 | @ $85.... | $ 10,200 | Added Sub: | | Enter total number of extra days. |
| | Driver+Trailer | 2 | @.35/mi | $ 700 | Added Tvl: | | Enter total number of extra hours. |
| Travel | Drivers | 1 | @.25/mi | $ 250 | | $ - | Extra Travel $ Dollars |
| 1000 | Pasengers | 2 | @.20/mi | $ 400 | | | |
| Miles | | | | | | | |
| | TOTAL SUB & TRAVEL......... | | | $ 11,550.00 | | | |
| | | | | | | | |
| | MOBILIZATON & DEMOBILIZATION: | | | | | | |
| | Man Hrs....... | 24 | | $ 576.00 | | | |
| | | | | | | | |
| | Total Sub,Mob, and Mileage............ | | | $ 12,126.00 | | | |
| | | | | | | | |
| TOTAL LABOR, SUB, & MOBILIZATION............. | | | | $ 56,963.72 | | | |

Figure 22: Labor budget

| Shift | Job |
|---|---|
| 1 | Mobilize & Start Board |
| 2 | Finish Board |
| 3 | Form Lower Wall |
| 4 | Finish Forming Lower Wall |
| 5 | Form Pump Well |
| 6 | Layout Upper Wall & Ancho |
| 7 | Set Jambs |
| 8 | Shoot Upper Walls |
| 9 | Corbel Brick & Layout Flue |
| 10 | Pour Lentil & Flue |
| 11 | Form Roof |
| 12 | Pump Roof |
| 13 | Misc |
| 14 | Strip Roof & Form Ramp |
| 15 | Pump Ramp |
| 16 | Pump Sill & Strip Ramp |
| 17 | Pump Floor |
| 18 | Misc |
| 19 | Inlet Well |
| 20 | Pump Well |

Figure 23: Shift schedule

## *CONCLUSIONS*

This project was a great success. Not only did we provide the customer an industry leading solution, we also completed the project two days before planned 20 shift schedule while being under budget. Thanks to the exhaustive planning that went into the project as well as the decades of experience that we were able to lean on, this project will provide the customer a solution for years to come allowing them to pass along value to their customers. Overall there were very few setbacks. Based on the material testing this furnace will allow the customer to run the furnace at their own schedule with relatively quick duty cycling.

## PROJECT SUMMARY

This project was initiated with a broad idea of what the customer wanted and a used frame of a furnace that was sitting in the back of their facility for months. Thanks to the industry leading refractory solutions and best construction team in the Tri-State area we were able to provide a solution that allows Al-Rec to provide a new product to their customers. Going into this project we were not sure about all the details, but we knew that if we paid attention to details and focused on any potential problems and potential opportunities to create flexibility that we could provide a long-lasting solution in a timely and cost conscious manner. Some aspects that we were extremely happy with were the lower wall and well construction. Going into construction we planned for multiple pours. After starting to assemble the refractory forms we decided that we could cut out time and reduce joints by building it for one continuous cast. This took a little extra custom forming but allowed overall time savings as well as a more monolithic structure true to design. The arches connecting the inlet and pump wells and the main holding area were also fantastic outcomes. Forming the unique ramp took some custom form building and extra time and will be an area to save time in future construction. Some areas where we had slight time setbacks were getting the refractory pump up and running. The Pump wasn't running properly, and we needed to bring a new one. Luckily, we had one available down the road at another facility. The inlet well was constructed from the refractory side which made removing the wood and screw forms take hours longer than planned. The door also took more modules than planned due to "one shot" application of the welding gun. Overall, we were able to come in about 5 thousand dollars under budget and complete the project with about a 32% gross profit.

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# APPENDIX A

Survey Results

**Customer Survey**

**Aluminum Furnace Construction**

This survey is used to arrange the importance of variables that effect the decision-making process when considering a project to build or repair an aluminum (or other) furnace in industrial applications.

How important is each feature or variable to you and or your company when considering the project scope of furnace construction?

| Please circle the appropriate answer. | 1=Low Importance | | | 5=high importance | | |
|---|---|---|---|---|---|---|
| Initial investment cost | 1 | 2 | 3 | 4 | 5 | N/A |
| Heat insulation efficiency | 1 | 2 | 3 | 4 | 5 | N/A |
| Worker safety | 1 | 2 | 3 | 4 | 5 | N/A |
| Durability (loading/unloading material) | 1 | 2 | 3 | 4 | 5 | N/A |
| Furnace service life | 1 | 2 | 3 | 4 | 5 | N/A |
| Construction time | 1 | 2 | 3 | 4 | 5 | N/A |
| Ease of maintenance | 1 | 2 | 3 | 4 | 5 | N/A |
| Start-up time | 1 | 2 | 3 | 4 | 5 | N/A |
| Thermal cyclability | 1 | 2 | 3 | 4 | 5 | N/A |

How satisfied are you with your current harvesting technology?

| Please circle the appropriate answer. | 1= very Unsatisfied | | | 5= very satisfied | | |
|---|---|---|---|---|---|---|
| Initial investment cost | 1 | 2 | 3 | 4 | 5 | N/A |
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| Construction time | 1 | 2 | 3 | 4 | 5 | N/A |
| Ease of maintenance | 1 | 2 | 3 | 4 | 5 | N/A |
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## Customer Survey

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|---|---|---|---|---|---|---|
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| Heat insulation efficiency | 1 | 2 | 3 | 4 | 5 | N/A |
| Worker safety | 1 | 2 | ~~3~~ | 4 | 5 | N/A |
| Durability (loading/unloading material) | 1 | 2 | 3 | 4 | 5 | N/A |
| Furnace service life | 1 | 2 | 3 | 4 | 5 | N/A |
| Construction time | 1 | 2 | 3 | 4 | 5 | N/A |
| Ease of maintenance | 1 | 2 | ~~3~~ | 4 | 5 | N/A |
| Start-up time | 1 | 2 | 3 | 4 | 5 | N/A |
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|---|---|---|---|---|---|---|
| Initial investment cost | 1 | 2 | 3 | 4 | 5 | N/A |
| Heat insulation efficiency | 1 | 2 | 3 | 4 | 5 | N/A |
| Worker safety | 1 | 2 | 3 | ~~4~~ | 5 | N/A |
| Durability (loading/unloading material) | 1 | 2 | 3 | 4 | 5 | N/A |
| Furnace service life | 1 | 2 | 3 | 4 | 5 | N/A |
| Construction time | 1 | 2 | 3 | 4 | 5 | N/A |
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| Worker safety | 1 | 2 | 3 | 4 | 5 | N/A |
| Durability (loading/unloading material) | 1 | 2 | 3 | 4 | 5 | N/A |
| Furnace service life | 1 | 2 | 3 | 4 | ~~5~~ | N/A |
| Construction time | 1 | 2 | 3 | 4 | 5 | N/A |
| Ease of maintenance | 1 | 2 | 3 | 4 | 5 | ~~N/A~~ |
| Start-up time | 1 | 2 | 3 | 4 | 5 | ~~N/A~~ |
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| Thermal cyclability | 1 | 2 | 3 | 4 | 5 | N/A |

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| Construction time | 1 | 2 | 3 | 4 | 5 | N/A |
| Ease of maintenance | 1 | 2 | 3 | 4 | 5 | N/A |
| Start-up time | 1 | 2 | 3 | 4 | 5 | N/A |
| Thermal cyclability | 1 | 2 | 3 | 4 | 5 | N/A |

**Customer Survey**

**Aluminum Furnace Construction**

This survey is used to arrange the importance of variables that effect the decision-making process when considering a project to build or repair an aluminum (or other) furnace in industrial applications.

How important is each feature or variable to you and or your company when considering the project scope of furnace construction?

| Please circle the appropriate answer. | 1=Low Importance | | | 5=high importance | | |
|---|---|---|---|---|---|---|
| Initial investment cost | 1 | 2 | 3 | 4 | 5 | N/A |
| Heat insulation efficiency | 1 | 2 | 3 | 4 | 5 | N/A |
| Worker safety | 1 | 2 | 3 | 4 | 5 | N/A |
| Durability (loading/unloading material) | 1 | 2 | 3 | 4 | 5 | N/A |
| Furnace service life | 1 | 2 | 3 | 4 | 5 | N/A |
| Construction time | 1 | 2 | 3 | 4 | 5 | N/A |
| Ease of maintenance | 1 | 2 | 3 | 4 | 5 | N/A |
| Start-up time | 1 | 2 | 3 | 4 | 5 | N/A |
| Thermal cyclability | 1 | 2 | 3 | 4 | 5 | N/A |

How satisfied are you with your current harvesting technology?

| Please circle the appropriate answer. | 1= very Unsatisfied | | | 5= very satisfied | | |
|---|---|---|---|---|---|---|
| Initial investment cost | 1 | 2 | 3 | 4 | 5 | N/A |
| Heat insulation efficiency | 1 | 2 | 3 | 4 | 5 | N/A |
| Worker safety | 1 | 2 | 3 | 4 | 5 | N/A |
| Durability (loading/unloading material) | 1 | 2 | 3 | 4 | 5 | N/A |
| Furnace service life | 1 | 2 | 3 | 4 | 5 | N/A |
| Construction time | 1 | 2 | 3 | 4 | 5 | N/A |
| Ease of maintenance | 1 | 2 | 3 | 4 | 5 | N/A |
| Start-up time | 1 | 2 | 3 | 4 | 5 | N/A |
| Thermal cyclability | 1 | 2 | 3 | 4 | 5 | N/A |

**Customer Survey**

**Aluminum Furnace Construction**

This survey is used to arrange the importance of variables that effect the decision-making process when considering a project to build or repair an aluminum (or other) furnace in industrial applications.

How important is each feature or variable to you and or your company when considering the project scope of furnace construction?

| Please circle the appropriate answer. | 1=Low Importance | | | 5=high importance | | |
|---|---|---|---|---|---|---|
| Initial investment cost | 1 | 2 | 3 | 4 | 5 | N/A |
| Heat insulation efficiency | 1 | 2 | 3 | 4 | 5 | N/A |
| Worker safety | 1 | 2 | 3 | 4 | 5 | N/A |
| Durability (loading/unloading material) | 1 | 2 | 3 | 4 | 5 | N/A |
| Furnace service life | 1 | 2 | 3 | 4 | 5 | N/A |
| Construction time | 1 | 2 | 3 | 4 | 5 | N/A |
| Ease of maintenance | 1 | 2 | 3 | 4 | 5 | N/A |
| Start-up time | 1 | 2 | 3 | 4 | 5 | N/A |
| Thermal cyclability | 1 | 2 | 3 | 4 | 5 | N/A |

How satisfied are you with your current harvesting technology?

| Please circle the appropriate answer. | 1= very Unsatisfied | | | 5= very satisfied | | |
|---|---|---|---|---|---|---|
| Initial investment cost | 1 | 2 | 3 | 4 | 5 | N/A |
| Heat insulation efficiency | 1 | 2 | 3 | 4 | 5 | N/A |
| Worker safety | 1 | 2 | 3 | 4 | 5 | N/A |
| Durability (loading/unloading material) | 1 | 2 | 3 | 4 | 5 | N/A |
| Furnace service life | 1 | 2 | 3 | 4 | 5 | N/A |
| Construction time | 1 | 2 | 3 | 4 | 5 | N/A |
| Ease of maintenance | 1 | 2 | 3 | 4 | 5 | N/A |
| Start-up time | 1 | 2 | 3 | 4 | 5 | N/A |
| Thermal cyclability | 1 | 2 | 3 | 4 | 5 | N/A |

## APPENDIX B

Furnace frame pictures

Frame figure 1

Frame figure 2

Frame figure 3

Frame figure 4

Frame figure 5


Frame figure 6


Frame figure 7


Frame figure 8


Frame figure 9

Frame figure 10

Frame figure 11

Frame figure 12

Frame figure 13


Frame figure 14


Framefigure 15

Frame figure 16


Frame figure 17


Frame figure 18

Frame figure 19


Frame figure 20

## APPENDIX C

Construction Photos

Figure 24 shows the inner wall of the holder and anchors


Figure 25 shows the jambs from the inside of the holder.

Figure 26 shows the inlet well and pump well from the inside of the holder.

Figure 27 shows the drains from the inside of the holder.


Figure 28 shows the jambs.


Figure 29 shows the inside of the holder before the roof was built.

## APPENDIX D

Final Product


Final product figure 1


Final product figure 2


Final product figure 3

Final product figure 4


Final product figure 5


Final product figure 6

Final product figure 7