**Concept Generation**

**Battle of Perspectives**

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| **Battle of Perspectives Chart** |
| Induction heating vs resistive heating |
| Conduction vs convection  |
| Digital feedback vs analog feedback |
| Electrical hardware control vs software control |
| Established methods vs novel methods |

The method of Battle of Perspectives allows ideas to be generated by comparing the dualities of the engineering areas that the design encompasses. They were generated by comparing two methods of the same goal such as heating, where induction heating and resistive heating are different but achieve the generation of heat. It also allows the designer to notice that the two compared tools might be used in concert. Strong ideas that came from this method was the method of control and the comparison between traditional and novel methods. Since this design will integrate with a similar product, some traditional methods will still be used but can use new methods to open the design space.

**Biomimicry**

Biomimicry is a way to relate biological systems to the design to try to solve the problem. The ideas that came from using biomimicry were a flowing river as an efficient flow channel, wind erosion in caves, termite mounds that efficiently transfer heat from the sun, and a counterflow heat exchanger in a wading bird’s legs. The ideas that this method provided were novel, but not many systems deal with heat transfer in the manner that would be useful to generate solutions.

**Rapid Brainstorming**

With rapid brainstorming all ideas that were thought of, no matter how unrealistic or complicated, were written down. This allows for ideas that may have been passed over because they are not realistic help create new ideas and allowing new points of view.

**Morphological chart**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Transfers heat** | **Gives feedback** | **Allows control** | **Allows efficient fluid flow** | **Mounts easily** | **Efficient coil shape** | **Measure Temperature** |
| Counterflow heat exchanger | Digital screen | Potentiometer | Twisting shape  | Clamping mechanism | Spiral  | Thermocouple  |
| Fin  | Dial | Radio frequency control | Straight piping | Picatinny rail | Helical  | Pyrometer |
| Brazed plate | LED lights | Mechanical control | Radial piping  | Suspension  | Pancake style | Infared Scanner |
| Envelope style heat exchanger | Program  | Software control  |  | Minimal material | Helical sweep with growth rate |  |
|  | Physical Buttons |  |  |  | Cylindrical  |  |
|  |  |  |  |  | Hexagonal cross section |  |

**Design Concepts**

The following are 100 concepts that were generated by using the above-mentioned methods. These concepts utilized the morphological chart, battle of perspectives, biomimicry, and crap shoot. Since the design features many subsystems, the ideas were organized into specialized categories in order to maximize creativity for each subsystem.

**Control**

1. Potentiometer with transistor temperature controller
2. Relays to switch between different temperatures
3. Microcontroller temperature controller with transistors
4. Radio frequency remote control
5. Voltage control
6. Current control
7. PWM control
8. Automated control through computer program
9. Quantum computer

**Flow**

1. Mechanically throttled valve
2. Passive flow control like casing treatment
3. Electric motor throttled valve like exhaust cutouts
4. Morphable fluid enclosure
5. 3D printed pipe
6. Multiple smaller inlets
7. Blend from rectangular to circular cross section shape
8. Abradable material pipe that changes shape as fluid flows
9. Gate valve
10. Ball valve
11. Pinch valve
12. Diaphragm valve
13. Needle valve

**Heating**

1. Induction and resistive heating combination
2. Gas heating with fuel source
3. Radiative heating with tungsten filament
4. Copper heating element using conduction
5. High frequency induction heating
6. Gas torch
7. Sunlight through magnification lens
8. Fan blowing hot air through coils
9. Sunlight heating water used to transfer heat
10. Nuclear heating
11. CO2 lasers
12. High power diode lasers
13. Microwave heating
14. TNT chemical reaction heating
15. Geothermal heating
16. Methane heating
17. Coal combustion
18. Resistive coil suspended in flow
19. High-temperature heat gun
20. Hydrogen fusion
21. Wood combustion
22. Lava
23. Friction heating

**Mounting**

1. Clamping mechanism
2. Weaver rail style mounting
3. JB weld mounting
4. Shelving brackets
5. 8020 extrusion
6. Unistrut
7. Electromagnetic mounts
8. Mounting stud and brackets
9. Picatinny rail
10. Composite plate with insulated thru holes
11. Suspension mounting
12. 3-point stinger mounting (good for thermal braking)
13. Permanent magnetic mounts
14. Friction based mounting
15. Zip ties
16. Duct Tape
17. Epoxy
18. Superglue
19. Magnetic levitation
20. Chains
21. Lug nuts
22. Systems of struts
23. Truss system
24. Arch bridge
25. Spring and Damper system
26. Metal 3-D printed mount

**Heat exchanging**

1. Topology optimized heat exchanger shape
2. Counter flow heat exchanger
3. Pancake induction coil and radial heat exchanger
4. Helically twisted heat exchanger
5. Spiral induction coil with cone shape heat exchanger
6. Fin heat exchanger
7. Envelope style heat exchanger to maximize surface area
8. U-style induction coil that also acts as cradle mount
9. Rectangular cross section cylindrical heat exchanger
10. Radiant floor with brazed plate heat exchanger
11. U-tube single pass shell
12. Two pass tube single pass shell
13. Two pass tube single pass shell with floating head
14. Rotary regenerator
15. Double pipe with axial fins on inner pipe
16. Hexagonal cross section
17. Termite mound channel-based heat exchanger
18. Liquid metal heat exchanger
19. Cylindrical tubing
20. Solid bar of steel
21. Radiator
22. Metal 3D printed heat exchanger

**Measuring temperature**

1. Thermocouple array
2. Pyrometer with thermocouple
3. Infrared scanner
4. Analog dial
5. Strain gauge
6. Digital Thermometer
7. Mercury thermometer

**Medium Fidelity Concepts**

Medium fidelity concepts were chosen from the list of 100 concepts as a way of filtering out good ideas that are reasonably feasible. These ideas are not the most efficient or robust but will still provide a solution to the problem. Since this design will feature many subsystems, the concepts were blended to create system level concepts. Some subsystems are shared between the medium fidelity concepts because knowledge of engineering concepts and recommendations by the customer constrained the choice of subsystem, such as the recurrence of induction and resistive heating. The engineering reason is that the environment the design is operating in will not allow for any chemical-based heating, which removes many heating concepts.

The first concept is induction heating, potentiometer for control, clamping mechanism for mounting, and counter flow heat exchanger. The potentiometer control allows for robust user control, because it is based on Ohm’s law. The clamping mechanism is modular and good for quick removal. The counterflow heat exchanger is a popular and efficient means of exchanging heat between two fluids. Since two fluids are not present, the fluid could be a solid piece of metal and perform similarly.

The next medium fidelity concept features induction heating, a microcontroller for temperature control, Unistrut for mounting, and a rectangular cross section. The microcontroller is cheap and can perform many functions reasonably well. The Unistrut is a modular product and has many accessories sold for it, while the rectangular cross section heat exchanger is an ideal candidate to exchange heat to the fluid.

Another concept includes induction heating, voltage control, mounting studs/brackets, and hexagonal cross section heat exchanger. The voltage control is a good choice because it is an easier parameter to control than current for induction heating. The mounting studs and brackets are a solution for mounting the coils because they have more freedom of installation then other mounting styles. However, they are not easily removable after installation. The hexagonal cross section was chosen because it is the cross section that the existing main heat exchangers use.

The fourth medium fidelity concept uses resistive heating, PWM signal control, weaver rail mount, and pancake heat exchanger. The PWM signal control is a simple means of control even if the signal is already amplified. Also, it works well with resistive heating which does not require alternating current, and PWM signals are difficult to form when controlling an AC waveform. The Weaver rail mount is a popular mount which also has many accessories like Unistrut. The pancake heat exchanger is a radially spaced heat exchanger and has shown promising designs in the industry but takes up a lot of physical space.

The final medium fidelity concept also uses resistive heating, combined with a relay, suspension mounting, and hexagonal cross section heat exchanger. The relay allows for extremely robust operation, because there is no degree of user control and the operation is purely based on electronic circuit fundamentals. The suspension mounting provides a solution for a mount that doesn’t conduct an appreciable amount of heat to where the mount attaches inside the test chamber.

**High Fidelty Concepts**

High fidelity concepts involve more complexity and might be a little more outside of the design box but can potentially provide great results. These are more novel concepts. All high-fidelity concepts will feature induction and resistive heating together because this gives the largest degree of control over the heat transfer, and since the main goal is heat transfer, these features are constrained.

The first concept features a potentiometer for control, composite plate with through holes, and a cylindrical heat exchanger. The potentiometer temperature control is the only high-fidelity concept that doesn’t involve a novel method but solves the problem of independent temperature control in the most direct manner. This allows for complete human control and is the most robust system out of the other control-based concepts. For a laboratory setting, this provides freedom of use and design. The composite plate with through holes is an ideal mounting solution that is strong and holds up well to extreme environments. It also is electrically insulative and allows a lot of freedom with induction coil geometries. If multiple coils are used, they must be mounted and electrically isolated so that the coils are not grounded.

The second-high fidelity concept uses the stinger mounting solution, voltage control, and helically twisted heat exchanger. The 3-point stinger mounting solution for the coil is extremely simple and allows for minimal contact between the coil and the structure of the mount. It is also not modular but could be made modular by making a thread version of the ends of the “stingers”. The helically twisted heat exchanger was chosen because it has potential for high efficiency. The helical twist allows vortices to form in the flow and enhances the bulk mixing of the flow, which would promote uniformity of the temperature distribution. It is not simple to manufacture but is a passive means of increasing efficiency.

The third high fidelity concept features a microcontroller, and U-style heat exchanger. The reason for the microcontroller is that this concept has an extreme amount of freedom and solves the problem of mounting and heat exchanger within one solution. The U-style heat exchanger acts as a cradle mount for the coils and can still provide heat transfer to the fluid. The microcontroller is clearly very programmable as it is an active control device.