New Life International Phase I Financial and Scientific Report

1. **Activities:** Clearly describe what activities were conducted under the GCE Phase I award, what results were obtained, and how those results directly support or refute the hypothesis you proposed in your original application. Please describe data gathered, experiments performed, project outputs, and summary conclusions.

Lets start with the end in mind: Phase I of the grant successfully created several inherently low friction "liquid ring type compressors" of various designs, with a wide range of efficiencies.

The activities to create these devices were structured as “exploratory journeys of discovery” rather than a canned preplanned design and roadmap approach. The first part of this effort was to explore counterintuitive approaches to developing-world appropriate compressors by getting rid of all the complexity of industrial systems such as depicted in this photo.


XAPV SKW Series Single Stage API 681 Vacuum Pump
Photo of A Set of Titanium Product (2 Pumps with 1 Gas-liquid Separator)

It should be noted this grant effort has helped produce a “disruptive innovation” in the sense that the compressor is not “good enough” to inflate a tire; but rather it demonstrates the feasibility of an inexpensive system that can become “more than good enough” for developing world wastewater aeration applications. Consider the picture of a typical industrialized liquid ring compressor/liquid ring vacuum pump and supporting subsystems. The end product of this grant makes all that stuff go away! The objective is to deliver air where needed!

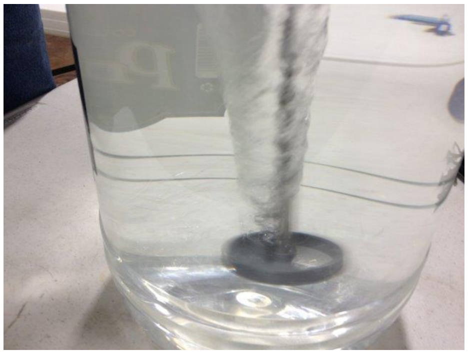
When we started, we began by spinning a variety of threaded rods and shapes in water to observe their ability to entrain air below a fluid’s surface.

One set of low cost experiments involved spinning three-fluted drill bits of various diameters backwards and observing the results at varying speeds. The observations can be summarized as follows: higher rotational speed, accompanied by a faster tip speed of the rotating object produced better results (more entrained air), but with higher energy demands.

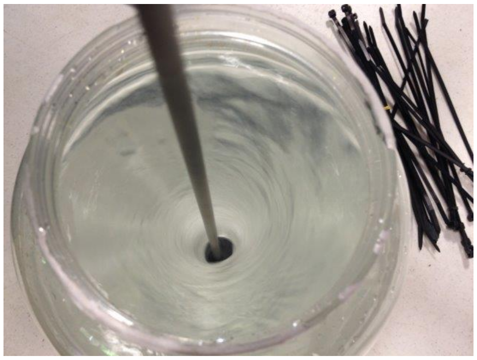
Spinning bits in water was a very quick way to learn a lot about forcing air into water in an unenclosed environment; and we discovered some interesting things. We really liked the three-flute idea used in some high-end wood bits. Each revolution picked up an extra swath by the third blade resulting in more air entrainment at lower rotational speed than a regular double-fluted bit. But we were in search of a more optimized shape that would be "flatter" such that it could be "toolable" from an injection molding standpoint for mass production. We wanted something that would gulp air and deliver it downward and compress it radially outward instead of inwardly as in conventional liquid ring compressors.

Part of the inspiration for the shape came from studying the tightening curves of a sea snail. While the sea snail curves depart considerably from making something "toolable", the idea of merging some of the geometry of a spinning wood bit to that of a sea snail was a fascinating concept.

The result was multiblade impellers that captured some of the curvature of a sea snail's helix with that of a wood drill bit. As we blended these two abstract concepts we forced the design to be "toolable" as if we were going to mass produce the results with injection molding using what is called a MUD (Master Unit Die). This technique is perhaps the lowest cost entry level approach to injection molding. Making the impeller "toolable" involved a lot of time and engineering thought. By making it "toolable" it forced us to address challenges such as: edge and corner radius', wall thicknesses, draft (a must if you wish to extract your part out of a mold), parting lines, gating (where you inject the molten plastic), ejector pin strategy, size of equipment, resin options, etc. Such tooling issues are normally left for the very last in a design project. Unfortunately it is often at the last moment the really bad news emerges that a time consuming creation cannot be manufactured! Some of our draftsmen were skilled at injection mold design and machining so the resulting parts became more intuitive from a production standpoint. Once we forced "toolability" into the designs we could always take deliberate time-saving shortcuts away from the mass production necessities and still maintain a clear return path back to a "production mode".



Our first impeller prototype was designed to press fit onto a hexagonal steel shaft and it displayed a remarkable ability to create a tight conical hole in the water, a needed property that would be exploited later with the evolving housing.



After a series of experiments with our first impeller design we set out to design a bearing strategy to support the impeller in a housing. While free-spinning our first impeller, we observed an interesting phenomenon whereby the conical vortex of air actually extended right through the center of the impeller. This gave rise to the off-the-beaten-path idea that maybe we could create an "air-bearing" that would have minimal solid contact between moving surfaces. During this process the design changed such that it was no longer convenient to drive the impeller with a steel rod. We chose to use a variety of different types of straight plastic rods and we threaded their very small inside diameter to accommodate a small single bolt. Impeller rotation was designed such that the bolt would tighten while spinning, rather than loosening.

Once the impeller was redesigned to accommodate a plastic drive shaft and a bearing strategy, we began work on building a housing around the impeller. We were still struggling to find a suitable wind turbine as we pressed forward with the first prototype and explored its ability to entrain air and deliver it below a fluid's surface. During the creation of the housing we also forced the design to be "toolable" for injection molding purposes to make sure whatever we invested time into was within striking distance of being mass reproducible. We were very pleased with the entrained air and the torrent of bubbles that spewed from the discharge. We discovered there were many unknowns and variables in the housing geometry as we took our impeller design and proceeded to build a housing around it. We settled on a mathematical geometry that was based upon an adaptation of the Fibonacci Sequence to create somewhat of a nautilus shell curvature.

<u>Late in the process, we eventually acquired a useable wind turbine</u>, but in its immediate absence we created a much larger version of the compressor to "bracket" the scalability of the compressor at a lower rotational speed (one forth less rotational speed, and able to deliver much more air to twice the depth). Our first large version utilized the same bearing strategy as our original small prototypes. Under the higher stresses of the larger version, the ABS plastic 3D prototypes simply locked up and refused to run for very long. This gave rise to designing some ceramic bearings and modifying the prototypes to accommodate "pre-production" ceramic bearings. Due to lead time constraints we took a shortcut in the ceramic bearing design and knowingly skipped adding some features we thought would be nice for production, but not necessarily for prototypes. The skipped features ended up being more critical than anyone would have guessed or imagined. As a result, our early ceramic bearings versions of the large scale compressor also faced lock-up challenges after running less than ten minutes. We did collect some good go-no-go information in the process. Certain ones of our impeller designs created a pulse type hammering whereby it acted as if we had a geometry that was creating "virtual compressor cylinders". While this may be interesting for further investigation, our first attempts with one such impeller design ended abruptly when the violent vibrations broke the drive shaft. This was particularly true when the port that feeds cooling water and maintains the dynamic fluid ring was intentionally blocked off just to see what would happen in a "failure mode". From these experiments we began designing new types of impellers and rotors that were more efficient and operated more smoothly once we incorporated ceramic bearings with better design features.

After installing the latest ceramic bearings in the most recent larger compressor unit we have been able to further substantiate the hypothesis that an inherently low friction compressor for develoing-world wastewater is achievable. This is perhaps the most critical data we have collected thus far on our largest and latest compressor design. The breakaway torque to start rotation of the wetted compressor from a dead stop averages out to be 0.013 N-M or 0.111 inch-pounds of torque to initiate rotation. Our current version of the small vertical axis wind turbine starts its rotation with a breakaway torque of 0.010 N-M or 0.093 inch-pounds. When the compressor and the wind turbine are coupled together, the breakaway torque required to start rotation is NOT additive; instead it defaults to the component in the system requiring the highest breakaway torque. Average measured breakaway torque values for the coupled system was: 0.013 N-M or 0.111 inch-pounds.

These breakaway torque values are surprisingly low, especially since we still have a few interference issues with the 3D printed prototypes and there is still room for improvement with the ceramic bearing features. In low wind conditions, rotation will tend to start earlier rather than later. The off-the-shelf wind turbine, while being produced commercially, really does need some engineering enhancements to more fully accommodate our applications. As these enhancements are completed, a further optimized compressor needs to be sized more accurately using the information collected thus far. We were actually surprised the small wind turbine could spin our larger compressor design. The current wind turbine can rotate our smaller prototype, without the higher efficiency bearings, at almost the exact rotational speed as needed for the larger compressor to operate. However the current wind turbine CANNOT survive the higher operating speeds required for optimum performance of our first small prototypes. Likewise when the small wind turbine spins the larger compressor, it does so, but its operational RPMs fall slightly short of optimum speed for the large compressor. Part of this has to do with the limitations of our overly simplified “wind tunnel” we used to keep costs down. When these engineering challenges are overcome, the creation of accurate performance curves described in our initial concept will be achievable.

We have made dozens of different 3D printed parts during this exploratory process and with each design change we have zeroed in to the point of being able to say: the concept of a developing world appropriate liquid ring type compressor/aerator is achievable, and we have identified the most critical areas for ongoing refinement (see application for Phase II ongoing funding for further details). Summary: the idea works! It just needs to be taken to a higher level.

2. **Challenges:** Have there been any additional internal or external challenges that you faced during the project? How were they addressed?

The biggest challenge faced was a major threat to the whole project. In the initial proposal, it was indicated the intention was to invent a “liquid ring type compressor” and match it to an available off-the-shelf, simple, inexpensive small scale windmill that had been well characterized. Shortly after receiving the Phase I grant funding, there was follow-up with the windmill provider who promised us a prototype for our research. It was at that point we discovered the windmill prototype had been destroyed in a high wind and would be very costly to replace (10-25% of our grant budget!). This was extremely disappointing. There was a temptation to quit and return the grant money. However, upon further reflection, it was concluded that maybe this particular windmill was too upscale and too expensive. For individual developing world families, something more economical was probably needed. The project was about delivering air, not necessarily about how to spin the device.

Pressing ahead, work on the core of the compressor design continued, and interesting discoveries were made. Early prototypes sort of worked, but they required high rotational speeds and what seemed to be too much energy … and the results were not dazzling. Further learning on the project led to perseverance.

About the same time, what appeared to be a very low cost developing world appropriate wind turbine was discovered. Futile attempts over several months to contact the manufacture were accented by a flood of:

unanswered emails, phone calls, and visits. The work continued without a wind turbine and then it was suggested to buy a cheap off the shelf windmill to start the compressor to windmill integration. The wind turbine was inexpensive enough, but it had terrible breakaway friction. The unit was placed out into a fierce wind. It required manual spinning to get it started. The windmill was completely useless for the application needed. It could not even start itself spinning under no load and a reasonable wind speed.

It was decided the grant was not about the wind turbine, but rather the feasibility or “proof of concept” for the compressor and efforts should not be dependent on the wind turbine interface; that could come later, even if it meant reinventing the wind turbine.

Meanwhile the prototypes were improving, but “lock up” problems due to the nature of asking 3D printed plastic to do things it simply was not capable of doing was challenging. The prototypes would run successfully, data collections were occurring, however; the plastic would overheat and the whole thing would seize up. A shift occurred to modify the 3D plastic parts to accommodate ceramic sleeve bearings and shafts.

A month before concluding the grant, contact from an apologetic owner of the wind turbine manufacturing company occurred. He offered a wind turbine (see photo at right). The resulting wind turbine had to be modified, and further data collection will continue from beyond the Phase I ending period. To more fully integrate the turbine to the compressors, some further modifications to the turbine are needed. But very late in the research, a missing link was found. This ongoing experience working with the compressor and wind turbine integrations has provided the confidence to press forward with this effort and without fear of disappointment ask for approximately $1 million of ongoing Phase 2 development funding.