Issues with current design construction essay

IntroductionOver the past decade, an increasing population coupled with rapidly depleting fossil fuel resources has driven the innovation of alternative energy sources. In recent years, there has been a strong focus of the use of clean and renewable energy sources such as solar, wind, hydro, geothermal and biomass, with a particular focus on their application for domestic and industrial situations. In New Zealand, 34% of residential energy consumption can be attributed to space heating applications, making it the largest single end use of energy[1]. Given the significant portion of energy associated with space heating applications, there is a drive for new innovations to reduce the heat and electricity consumption in buildings. Ground-source heat pumps (GSHP), or geothermal heat pumps, have received much attention in recent years. Their efficiency, potential for energy savings and environmental protection when applied to heating and cooling applications means that this technology has good prospects for development[2]. Basically, a GSHP transforms the Earth’s energy into useful energy. It provides low temperature heat by extracting it from the ground and enables cooling by the reverse of this process. The principle allows this technology to produce more energy that is uses making it a more efficient alternative to air and other source heat pumps due to the stable temperature of the ground. GSHP’s have the advantages of less energy consumption, reduced need to supplement heat, more stable heat source, simpler design and less maintenance[2, 3]. However, although GSHP technology has better performance than conventional heating systems, there are still some potential areas for development to further improve the technology. One development area that has been identified is the coupling GHSP systems with latent heat thermal energy storage (LHTES). Research into LHTES is steadily increasing due to its excellent possibilities for thermodynamic efficiency and space savings. LHTES systems store heat through the phase change process, providing an effective storage method due to their high-energy storage density and the small temperature variation between storing and releasing heat[4]. Materials with a phase change that are suitable for temperature critical heat storage are commonly called phase change materials (PCM). Although PCM are widely used in building applications for energy storage and temperature control, the application of PCM to improve the performance of GSHP has not been, to date, studied nearly as extensively. Technologies for incorporating PCM into GSHP systems have been investigated and the potential for modifying conventional soil with phase change materials has been highlighted, with these systems possessing the capability of significantly improving the coefficient of performance of the heat pump system, resulting in significant energy savings in space heating applications[5, 6]. This research paper continues the investigation begun by Zongyu Gu, under the supervision of Professor Mohammed Farid, on the application of high conductivity phase change materials in GSHP applications. The aims of the research are to develop a computer simulation for the underground heat transfer processes with and without PCM and to demonstrate the benefit of using high conductivity PCM in GSHP applications through both the simulation and through experimentation, by monitoring the temperature responses in the ground. The successful implementation of a LHTES system with a GSHP system poses an opportunity to significantly reduce the installation cost of GSHP systems, improve the coefficient of performance of the heat pump and further reduce energy usage for domestic, and potentially commercial, space heating applications. Literature ReviewOverview of GSHPDesign BasisHeat pump operation involves the extraction of heat from a heat reservoir and the delivering of this heat to a space that we wish to heat up. Conversely, air conditioners extract excess heat from a space that we wish to cool down and reject that heat into a heat sink. The efficiency of heat pump systems is quantified using the coefficient of performance (COP) which is effectively a ratio of the heating or cooling provided over the electrical energy consumption of the system. For high energy efficiency, the heat reservoir or heat sink in these applications would ideally be warmer or cooler respectively than the space we are trying to control and experience minimal temperature fluctuations during periods of operation. Although the atmosphere is a common choice of heat reservoir or heat sink, the efficiency of an air to air heat pump is high only when the outside ambient temperature is moderate, and the performance of these systems experiences drastic reductions at ambient temperature extremes[6]. Over the past few decades, increasingly more research has been dedicated to the application of ground source heat pumps. The slow transportation of heat through soil coupled with its high heat storage capacity make the ground an ideal medium to act as a heat reservoir or heat sink as the temperature, at depth, remains relatively constant all year round[7]. The temperature of the ground is lower than the ambient air temperature in the summer and higher than the ambient air temperature in the winter. This difference in temperature can be utilised in heat pump operation to reduce the heating and cooling loads of the device by extracting heat from the relatively warm ground in the winter and rejecting heat to the relatively cold ground in the summer. Given the increased coefficient of performance associated with GSHP and their reduced energy demands, the technology has become well established with 550, 000 units installed worldwide and with 80% of these installed domestically[8]. Physical ImplementationThere are two general configurations employed in the practical implementation of GSHPs for domestic purposes: horizontal and vertical. The horizontal configuration involves burying tens of metres of heat transfer pipes connected in either series or parallel below ground level, where a constant temperature is maintained. This configuration is economically preferred when adequate surface area is available [8, 9]. Conversely, the vertical configuration involves the drilling of a borehole up to 150m deep and installing the pipes vertically. Although this configuration is generally more expensive to install than the horizontal loop, it requires less piping as the ground temperature is lower at increased depth. The use of vertical GSHPs is widely used in areas with limited space, such as cities with a high building density, or where minimal disturbance of the landscape is desired[8, 10]. Issues with current designAlthough this technology has been widely implemented and does display better performance than conventional air heat pump systems, there are still issues with the design that, with further development, would greatly improve the systems performance and availability to consumers. The biggest barrier to further implementation is the installation cost associated with these systems. At present, the recovery of the capital costs in installing these systems takes many years due to the net annual savings being much less than the cost of implementation[9]. On top of this, increasing the efficiency of these systems has been identified as another area for improvement. It is known that GSHP systems can achieve better energy performance in environments where the heating and cooling loads are balanced. Due to the low thermal conductivity of soil, the energy in the vicinity of the installed pipes is rapidly dissipated during heat pump operation and as a result, the temperature of the heat transfer fluid continues to decrease along with the COP of the heat pump. Therefore, when there is unbalanced loading, the energy efficiency of GSHP systems remains low [6, 10]. A number of investigations have shown that the system performance of heating and cooling systems can be improved by employing integrated design approaches, particularly the use of phase change thermal storage[5, 10-12]. Although this system has been identified as an effective means to improve heating and cooling applications, little research has been dedicated specifically to the application of PCMs to GSHP applications, particularly phase change materials with high conductivity. PCMOverview of thermal energy storageThermal energy can be stored as sensible heat or latent heat. Although thermal energy is commonly stored in many applications as sensible heat by increasing the temperature of a storage medium such as water, there is a noticeable shift towards the implementation of latent heat thermal energy storage (LHTES) systems. LHTES systems store heat through the phase change process, providing an effective storage method due to the materials high-energy storage density resulting in less weight and volume than conventional storage systems as well as the small temperature variation between storing and releasing heat[4, 5, 13]. Figure 1 below illustrates the storage of sensible and latent heat in a material. Notionally, in this research, the phase change process refers to the solid-liquid phase change in order to avoid the difficulties high pressure and volume vapour phase storage causes. Figure - Sensible and latent heat storage[4]Design considerations for PCM applicationFor the successful implementation of LHTES systems, a comprehensive understanding of the thermophysical properties of the phase change material being used in the heat exchanger is required. Farid et al. and Zalba et al. have carried out extensive reviews on phase change materials, their properties and their applications and have identified that the important characteristics for application are thermal properties, physical properties, chemical properties and economic properties[11, 12]. Farid describes that specifically, the PCM should have a melting temperature lying in the practical range of operation, melt congruently with minimum sub-cooling and be chemically stable, low in cost, non-toxic and non-corrosive. He then goes on to further describe that for most applications PCMs should first be selected based on their melting temperature. Saturated methyl ester fatty acid displays excellent thermal properties, a suitable melting temperature and stability with no corrosion, toxicity or sub-cooling, a low vapour pressure, no phase segregation and commercial availability; making it ideal for application in domestic LHTES systems[14, 15]. However, practical difficulties arise with the use of this compound due to firstly, liquid leakage flow during the melting process and secondly, their low thermal conductivity (~0. 2 W/m°C). The former of these disadvantages can be eliminated by form-stable PCM, which consists of a fatty acid PCM as the core and a matrix containing a supporting material[14]. For the latter, many previous works have indicated that there are methods to successfully enhance the thermal conductivity of the PCM. Heat transfer enhancementA major drawback in maintaining the required heat exchange rate between PCM and the heat transfer fluid in GSHP applications is their low thermal conductivity. However, there are several suggested methods to enhance the heat transfer in a LHTES system. The use of finned tubes of different configurations has been proposed by a number of researchers such as Agyenim et al.[16] who investigated longitudinal finned system and Ismail et al.[17] and Padmanabhan et al.[18] who investigated axial finned systems. Many researchers have reported increasing the heat transfer through the combination of PCM with highly conducting materials, for example embedding the PCM in a metal matrix structure, a graphite matrix or PCM dispersed with highly conducting particles[19]. Bauer and Wirtz[20] reported the use of thin aluminium plates filled with PCM, Tong et al.[21] reported the use of a high porosity water and aluminium matrix, Elgafy and Lafdi[22] reported on carbon nanofibres filled paraffin wax and Khan et al.[23] reported on the heat transfer characteristics during solidification in the presence of reinforcements including graphite, alumina, iron and copper in an aluminium-silicon and lead based composite. The heat transfer enhancement method with the most promise appears to be the embedding of PCM in a graphite matrix as proposed by Mehling et al.[24] and Mills et al.[25]. The main advantage of this heat transfer enhancement method is the increase in conductivity and heat transfer without a significant reduction in energy storage as well as the simplicity involved in the formation of the matrix. Potential disadvantages with this method include the directional dependency of the thermal conductivity in the matrix and the reduction in the specific latent heat available. Mills et al. investigated the fabrication of a graphite matrix from flake graphite, impregnating the matrix with paraffin wax and determining the thermophysical properties of the composite. In addition, these experiments detail each step of the process, from raw material to application and identify that the paraffin wax and graphite composite has a thermal conductivity 20-130 time greater than that of pure paraffin wax[25]. The use of graphite has also been studied by other researchers such as Sari and Karaipekli[26] who focussed on the characterisation of thermal properties of a palmitic acid and expanded graphite composite, reporting the thermal conductivity of the composite to be 2. 5 times higher than that of pure palmitic acid. Mazman et al.[19] compared the use of a graphite matrix impregnated with PCM to the addition of stainless steel and copper pieces to PCM. They reported that the best results for enhancing heat transfer were obtained in the experiments with the graphite matrix due to its large thermal conductivity range. Integration of GSHP and PCM systemsPrevious proposals and experimental researchMore recently, the focus of energy research in the area discussed has shifted away from the investigation of GSHP systems themselves and towards the potential improvements available for these systems, particularly those related to energy storage. A significant portion of the literature investigates specifically the application of PCM to GSHP systems as a way of integrating LHTES and improving the efficiency. However, other methods of energy storage have been proposed such as that in a patent filed by Xu[27]. He proposes an energy storage function that is achieved by the flowing fluid through different piping configurations while using reversing valves. In addition, Zhai et al. completed a review on integrated approaches of ground-coupled heat pumps, identifying that adopting an integrated approach would not only improve the efficiency of the system but also reduce the initial cost of boreholes. He suggested integrating GSHP systems with solar energy, cooling towers, thermal storage technologies, conventional air conditioning systems, dehumidification systems and heat recovery technologies, concluding that for building with a heating dominated load, the integration of a solar and thermal system showed the greatest potential for efficiency improvements and energy utilisation. His review on thermal storage suggests ice storage, a direct ground heat exchanger, the utilisation of rainwater, soil cold storage and the use of PCM; referencing investigations that had validated the use of each of these systems. He identifies the need for further investigation into a control strategy based on the climatic conditions in order to identify optimal operation of each system[10]. Although other methods of energy storage have been proposed and validated, the remainder of this review focusses of the previous proposals and experimental research related to the integration of GSHP and PCM systems only. Leon proposed a closed GSHP where the heat transfer fluid is in thermal contact with an encapsulated PCM. This design specifies that the PCM must have a high latent heat of transition and undergo a phase change during the normal operating conditions of an air to water heat pump system. The use of two different phase change materials was proposed – corresponding to the winter and summer conditions. The winter configuration involves the encapsulation of a PCM material that undergoes transition at a temperature approximately 10°F below the mean winter undisturbed soil temperature, while the summer configuration involves the encapsulation of a PCM material that undergoes transition at a temperature approximately 10°F above the mean summer undisturbed soil temperature, to account for heat loss and heat gain from the soil respectively. The proposed utilisation of two different PCMs operates on the assumption that there is a significant difference between the summer and winter ground temperatures. However, many researchers[3-5, 7, 10] have identified that the temperature of the ground remains relatively stable throughout a four season cycle. The temperature and rate at which the latent heat is released from the PCM is said to stabilise the temperature of the heat transfer fluid so that it provides an inlet condition to the heat pump that ensures a high coefficient of performance[6]. Leon further claims that in addition to stabilising the heat transfer fluid temperature, the improved design involving the integration of PCM also reduces the length and area of piping required for installation of the system. The presence of the PCM is said to slow the rate at which heat is transferred from the earth, and allows the temperature of the earth to remain closer to its undisturbed temperature for longer periods of time due to the increased time for the recovery or dissipation of heat. This patent identifies that maintenance of a constant temperature at the inlet to the compressor results in approximately double the efficiency when compared to heat pump systems that are subjected to extreme variations in temperature[6]. Similarly to the invention proposed by Leon, Nangle also proposed an invention which incorporates the use of PCM with a ground source heat pump. This system also claims a reduction in the length and area of the pipe, and therefore reduced installation cost. However, conversely to the invention proposed by Leon, this system uses only one PCM in its design, to be used for both summer and winter conditions. Nangle suggested a device similar in structure to that of a double pipe heat exchanger which includes an inner and outer layer that contains PCM in the jacket between these two layers. He identifies that the storage system acts to " smooth out a series of thermal load peaks", ensuring that the transfer of heat from the ground is of a constant value and is continuous[9]. In addition to the patents proposed by Leon and Nangle, many similar themed patents have been filed in both the United States and United Kingdom. Moilala and

Gasik[28] proposed the application of PCM to a heat exchanger. They identified the suitability of PCM for short term storage and identified that the operating state of the system should be as close as possible to the transition temperature of the PCM, as was also identified by Farid et al.[11] and Zalba et al.[12] in their respective reviews of PCM. Ally et al.[29] proposed a heat pump system that can be coupled with a hybrid class of PCMs. The PCMs described in this invention are made of a solid adsorbent coupled with hygroscopic materials or another hydrophilic substance with suitable properties. In addition to the proposal of such systems through patents, there has been significant PCM and GSHP coupled systems. Benli 2008 carried out an investigation of a GSHP with a calcium chloride hexahydrate salt hydrate PCM system in relation to its application to greenhouse heating. In this study, the PCM was stored in a tank with a diameter of 600mm and a length of 1500mm that was situated in the greenhouse. By considering the mass flow rate of the water-antifreeze solution, the electrical power input to the compressor, and temperatures at multiple positions in the system, he aimed to determine the COP of the heat pump, and of the overall system, for different times during the day. The COPSYS and heat transfer rate were calculated from nine empirical correlations[7]. Based on heating experiments carried out in Turkey between 1 September 2005 and 30 April 2006, this study identified that when the mass flow rate of the heat transfer fluid increased, so did the COPSYS due to a corresponding increase in heat transfer. It was also identified that COP values of the GSHP are higher than those for conventional air-air heat pumps, specifically when applied to these low temperature conditions. The COPHP and COPSYS were found to be between 2. 3-3. 8 and 2-3. 5 respectively, with their value being highly dependent on the temperature within the greenhouse. The study identified that, in this district, the integration of calcium chloride hexahydrate PCM with GSHP was validated[7]. The above result was further validated in 2009. One year after his previous publication, Benli was involved in a similar investigation, working with Durmus to further evaluate the implementation of a coupled GSHP and PCM systems to greenhouse heating applications. The results from this second investigation led to the same conclusions as his previous work[4]. Finally, Agynim and Hewitt 2010 carried out an investigation to evaluate the heat transfer characteristics of longitudinally finned RT58, a heat transfer enhanced PCM. This investigation was part of a wider study to evaluate the most appropriate PCM to take advantage of off peak electricity tariff in relation to space heating and cooling. Experimentation was carried out using 95kg of RT58 which contained an embedded finned tube in the centre and was further encapsulated in a long copper cylinder. This investigation iterated the need for heat transfer enhancement techniques when GSHP and PCM system are integrated, with the enhancement of heat transfer using fins being shown to be able to reduce the store size by 30%[16]. Simulation of integrated systemsIn addition to the validating of coupling GSHP and PCM systems through experimentation, significant research has been directed towards modelling the heat transfer within the system through simulation, with the simulation results consequently being validated using experimental methods. Given the complexity of the heat transfer equations related to the integrated system, the use of numerical methods is the only largely appropriate approach[12]. Vakilaltojjar and Saman 2001 investigated the application of an energy storage system containing sections of different PCMs with different transition temperatures for use in air conditioning applications, specifically in space heating and cooling applications. They compared the results of two finite elements method models, each with different assumptions. In both cases, the Neumann Solution boundary conditions were used, that is, the value of the solution derivative at the boundary was specified. In addition, the effect of PCM thickness and fluid passage gap are also investigated to determine how they affect the storage performance. It was assumed for this study that heat transfer was unsteady and two dimensional. Additionally, it was assumed for all models that PCM supercooling effects are neglected, along with axial conduction in the PCM, heat transfer fluid and container walls, the heat capacity of the heat transfer fluid and container walls, and natural convection in the PCM liquid during melting or solidifying. Furthermore, transient convection was considered as a series of steady state problems. The models investigated aim to validate additional assumptions[13]. Specifically, Vakilaltojjar and Saman were aiming to investigate whether the assumption that when the inlet air temperature and the melting point of the PCM are similar, the term associated with sensible heat can be ignored. They identify that the selection of an appropriate iteration grid size, and therefore number of nodes, is important in order to result in an accurate solution coupled with a reasonable computation time. This research concluded that the results from the two models were indistinguishable, validating the previous assumption, as well as identifying that performance of the system can be improved by using smaller air gaps and thinner sections of PCM. However, in assessing these results it is important to consider that this simulation outcome has not yet been substantiated through experimental testing[13]. Caliskan et al. 2011 performed both exergy and energy analyses on a thermal energy storage system coupled with a solar GSHP. The exergy analysis is based on the second law of thermodynamics and is identified by Caliskan et al. as a significant gap in current literature where thermal energy storage systems are considered, reporting on many articles that have considered only energy analysis. The exergy efficiency is based on reference conditions of 1 atm of pressure and a temperature ranging from 0°C to 25°C at a constant flow rate[30]. These energy and exergy analyses were applied to a solar GSHP integrated system that was installed in a 120m2 house, considering a period of operation from May to October. The results yielded an energy efficiency of 42. 94% and a maximum exergy efficiency of the system to be 40. 99%. The exergy analysis identified that the magnitude of external losses due to thermal energy losses is much smaller than internal losses due to irreversibility. It can be identified that the maximum exergy efficiency is lower than the energy efficiency. Caliskan et al. proposes that exergy analysis is a more useful method for identifying losses and efficiencies in thermal energy storage systems than energy analysis, reporting that the exergy efficiency gives a " true picture of the system and its performance"[30]. However, by far the most commonly used and verified is the enthalpy model. The enthalpy method employed in investigations carried out by Han et al.[31], Wu and Zheng[3] and Wang et al.[32] sets the enthalpy and temperature as two variables and are based on similar assumptions including: the PCM phase change is isothermal, natural convection in the PCM liquid is negligible, the density, property of the phase change and movement of the solid liquid interface during phase change are not considered and finally, the PCM is homogeneous and isotropic and its thermophysical properties are different for the solid and liquid phases but are independent of temperature in these states. These researchers carried out simulation programmes in MATLAB. Wu and Zheng 2005 proposed the modelling of a solar GSHP system using a control volume enthalpy based method. They conducted a comparison of the soil temperature variation between a system without thermal storage and a system with thermal energy storage. The climatic data used in this simulation was obtained from Harbin which has an average yearly temperature of 5. 2°C. The system was modelled on a 5 month heating period, followed by a seven month recovery period. Figure 3 illustrates the results of the simulation[3]. Curve A: Initial temperature of soilCurve B: Temperature distribution in soil after 5 month heating operation in Year 1Curve C: Temperature after 7 month soil recovery in Year 1Curve D: Temperature distribution in soil after 5 month heating operation in Year 2Curve E: Temperature after 7 month soil recovery in Year 2Curve F: Temperature distribution in soil after 5 month heating operation in Year 3Curve G: Temperature after 7 month soil recovery in Year 3Figure - Variations in Soil TemperatureThese results illustrate that if heat is only extracted from the soil; the soil temperature steadily decreases, resulting in low system efficiency. Furthermore, it is impossible for the soil to return to its initial temperature if no heat is supplied back to the soil. This study goes on to identify the need for thermal energy storage, suggesting a system that ideally ensures the heat extracted from the soil is equal to the heat stored within the system. It is identified that PCM thermal energy storage when integrated with the solar GSHP system can improve the heating COP from 2. 8 to 3. 4, significantly improving the performance in cold climates[3]. Wang et al. 2010 proposed the modelling of the system using finite differences enthalpy based method in three dimensions, and validated this method using experimental data. Experimentation was carried out using 250kg of CaCl2. 6H20 encapsulated in a polyethylene plastic container which was further insulated using polystyrene and both the inlet and outlet temperature of the LHTES system were measured. Conversely to Vakilaltojjar and Saman, Wang et al. divided enthalpy into sensible and latent heat components[32]. The results from this experimentation indicated that during the storage process, the simulation data was higher than the experimental data and the opposite effect illustrated during the discharge process. A similar discrepancy was shown when the storage and emission heat of the experimental and simulation data was compared. However, despite these minor discrepancies, the research concluded that the simulation results sufficiently approached the experimental results, illustrated similar trends and therefore validated the used of the heat transfer model used[32]. Dehdezi et al. 2012 performed numerical simulations to model the temperature variations within the ground in order to study the potential of PCM modified soil for application to GSHP systems. The numerical method used was a one dimensional, finite difference, heat transfer model based on the enthalpy method. Using Arizona climatic data between July and October in 1996, the temperature variation at a depth of 1m was predicted. The study identifies that modifying the soil with 40%vol PCM and 80%vol PCM could reduce the maximum soil temperature by approximately 3°C as well as significantly reducing the temperature variation. The simulation results are shown in Figure 2[5]. 1m1mFigure - Temperature variations at a depth of 1m in control soil and PCM modified soilIt was reported that this reduction in temperature identifies that the COP could be improved from 7. 6 to 8. 9, which corresponds to an increase of more than 17%[5]. However, although the PCM does reduce the soil temperature, there is still a noticeable increase in overall soil temperature over the 90 day period the simulation investigated, identifying the need for further improvements in the system design. Relevant issues identified in the literatureIt appears from a comprehensive literature review that there has been no significant investigation into the application of PCM; in particular high conductivity PCM, in GSHP applications. Coupling LHTES with these systems has been found to increase efficiency, reduce both operating and installation cost, and provide a superior space saving alternative to current systems. The research identifies that further improvement in efficiency could be experienced through the use of appropriate heat transfer enhancement techniques; however this is yet to be validated and is worth investigation. Overall, the research further indicates that simulation of GSHP systems integrated with LHTES systems appears to be successfully modelled using an enthalpy based finite differences method. However, there is a significant lack of research validating the simulation results through experimental testing. Objective of investigationThis study aims to provide and validate a model which represents the underground heat transfer processes of a GSHP, with and without PCM, by employing numerical methods and the finite difference method. It is hoped that by validating this model through both simulation and experimentation, we can predict the thermal responses of the system with the enhancement of high conductivity PCM with a reasonable level of accuracy. In doing so, this study hopes to demonstrate the benefit of using high conductivity PCM in GSHP applications and develop insights into method to increase the efficiency of these systems. Research significanceIt is hoped that a better understanding of the thermal behaviour of PCM and PCM-graphite thermal storage systems when applied to GSHP technology will help to advance space heating research. The ultimate objective of this research is to determine the effectiveness of the application of high conductivity PCM to GSHP systems, so they can be better designed to show increased efficiency and cost and energy savings, therefore, displaying the potential for more widespread installation. Simulation Basis ChangeThe initial simulation work used MATLAB to numerically solve the one dimensional heat equation using the finite differences method and considered the cycling of the condenser on a time basis. The condenser cycling was controlled by using boundary conditions to set the condenser on for a certain amount of time, corresponding to a temperature of approximately 50°C and off for a certain amount of time, corresponding to a temperature of approximately 20°C. However, initial analysis of the results contradicted literature, showing for the case with PCM and graphite in the annular region that the temperature fluctuation was more severe and the soil temperature increased more rapidly than the case of an annular region filled with soil or PCM. As outlined above, the simulation alternated the water temperature between two levels, fixing it for a certain period of time at each value regardless of the composition of the annular region. Due to the high thermal conductivity of graphite, the heat extracted from the soil increased. This identified that the simulation should operate the condenser based on an energy basis, fixing the energy absorbed in one cycle to a constant value. Consequently, when graphite is used, the energy will be extracted at a much higher rate but for a shorter period of time. The figures below illustrate the change in the system.