ISSN Application No. 21651

# Journal of Mechanics and Thermodynamics

Volume No. 13
Issue No. 1
January - April 2025

ENRICHED PUBLICATIONS PVT.LTD

JE - 18,Gupta Colony, Khirki Extn,
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ISSN Application No. 21651

# Journal of Mechanics and Thermodynamics

## Aims and Scope

Journal of Mechanics and Thermodynamics publishes theoretical and practice oriented papers, dealing with problems of modern technology (power and process engineering, structural and machine design, production engineering mechanism and materials, etc.), Materials and Design Engineering, Vibration and Control, Thermal Engineering and Fluids Engineering.

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# Green Approach for Comfort Cooling In Domestic Application

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## A B S T R A C T

*In the present era of sustainable energy 'Green' has evolved as the buzzword, which dominates every new research and developmental work. It has compelled us to review the potential of an equally dynamic and sustainable form of comfort conditioning technology. This paper reviews the potential of vapour absorption comfort cooling method for domestic application. It thrives on the probability of using solar thermal energy as the source of power to run the VARS cycle. On the whole this paper will try to provide us with a general platform to understand the importance of cooling in present world and to appreciate the innovative efforts of scientific community towards the global concern for clean, green and sustainable technology.*

***Keywords: comfort, cooling, air-conditioning, absorption, solar.***

## I. INTRODUCTION

Refrigeration process can be broadly classified into Natural Refrigeration & Artificial Refrigeration. Natural Refrigeration is that where low temperature is achieved by using some natural medium, like natural snow. Artificial Refrigeration, on the other hand, was discovered only few centuries back when human civilization evolved into a more scientific and modern society. And this art of natural refrigeration turned into a comprehensive science of low temperatures. [2][3][12] Modern day refrigeration technology developed on the fundamental principal of 'heat transfer through phase change or evaporation of liquids at low pressure', enunciated by Darwin. The conventional method of artificial cooling used today are as follows: [2][3][12]

1. The 'vapour compression system', which transfers heat from through alternate cycle of compression and expansion. (Figure 1)
2. The 'vapour absorption system', which produces cooling effect through a thermodynamic process of phase change without using compression. (Figure 2)

Both the above mentioned systems produces cooling effect through evaporation of refrigerant at a lower pressure, but on the one hand the vapour compression system first compresses and then expands (suddenly) the refrigerant before causing evaporation, while in case of absorption system compression process is replaced by absorption-generation unit, wherein direct heat energy is utilized for producing lower temperatures, through a sequential thermodynamic phase change process

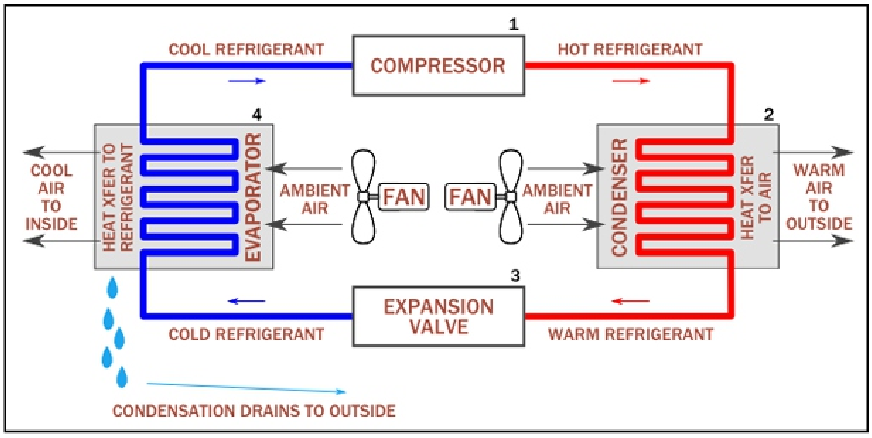


**Figure 1:** Line diagram of a simple conventional vapour compression refrigeration cycle. [4]

Energy concerns are rising in the developing countries like India and the scientific community is constantly looking for various avenues and alternative resources of energy or at least alternative methods of saving the energy. The run for this energy efficient system has raised many questions on wasting a large chunk of conventional sources of energy on the leisure applications like comfort conditioning systems. Therefore it's a high time to think and execute our energy conservation regime into the niche sector of comfort condition systems. Now since the comfort cooling requirement increases with the rise in atmospheric temperature, therefore this corresponding availability of increased solar insolation makes the solar powered cooling systems a potential solution for a sustainable technology. [10]

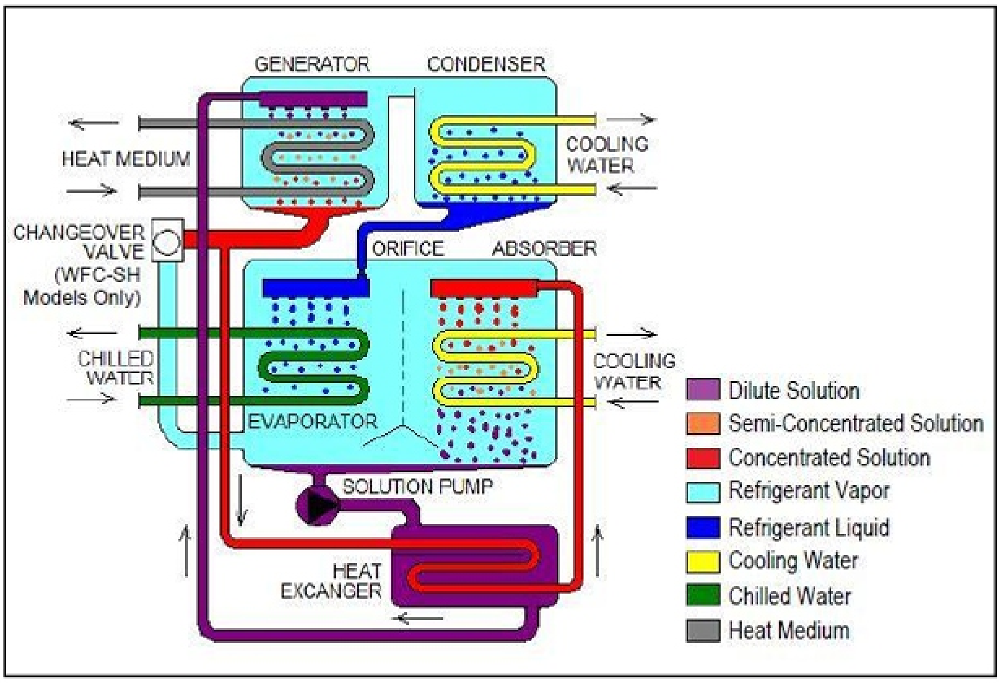


**Figure 2 :** Diagram of vapour absorption refrigeration system. [5]

**Green cooling system**

Conceptually, an absorption-refrigeration machine (Figure 2) corresponds to the vapour-compression refrigerator in which the compressor is substituted by four elements: a vapour absorber, a Pump (replacing a compressor), a generator or boiler, and a valve to recycle the absorbent liquid. Its great advantage is that this cycle requires very less work to operate the pump as compared to the energy required to run the compressor.

But the major drawback of this technology is that it requires high grade of energy (i.e. electricity) to produce and supply a low grade energy (i.e. Heat) for the Generator unit , to produce cooling effect, therefore it is suitable or commercially feasible for large commercial installations only and not for the small or domestic comfort cooling applications. [7]

This limitation of the VARS system can be targeted and efficiently met by utilizing the solar thermal energy to provide this Heat energy to the Generator unit instead of using the conventional electricity to run the system. Solar assisted vapour air-conditioning system works on the principal of conversion of thermal energy from the sun into useful work. This is done by collecting solar radiations/thermal potential, through solar collectors and transferring it to the generator unit. The vapour absorption air-conditioning system acts as an intermediate agent, which transforms the heat energy from solar circuit into the desired refrigerating effect for the airconditioned space. [8][9]

A workable Green comfort cooling system may consist of the following elements: (Figure 3)

1. Solar collector loop
2. Vapour absorption system (LiBr2 + H2O)
3. Air-conditioning loop

In solar collector loop, solar energy is utilized to generate very high temperature in order to heat up the working fluid (in this case, water). Solar collectors are used to collect the incident radiations of sun, and the heat is transferred to the working fluid,

which is made to flow through the solar collector.

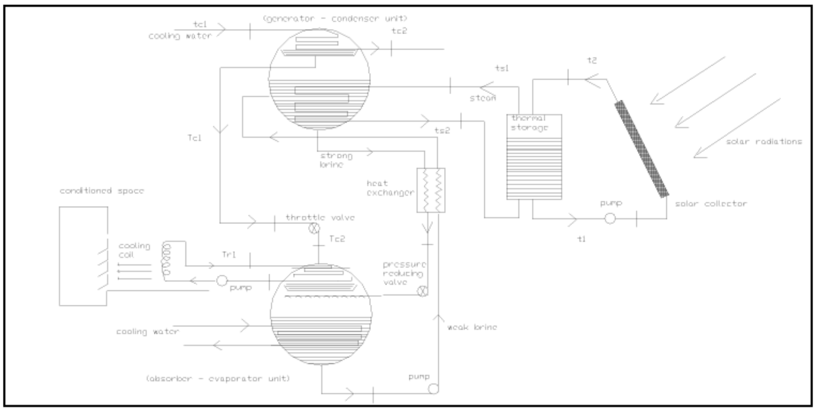


**Figure 3:** Schematic Diagram of a Solar Powered VARS for Domestic Comfort Cooling Application.[10]

Now the steam generated by the solar collector loop is passed through the generator unit of V.A.R.S., where the LiBr2 + H2O solution is heated by this steam, and h2o (refrigerant) is vaporised and reaches condenser, whereas, the remaining libr2 solution is sent back to the absorber through pressure reducing valve by the use of gravity forces. The refrigerant vapours in the condenser are cooled at constant pressure to become saturated liquid (because heat carrying capacity of liquid is more than that of a gas). Now, this saturated solution of refrigerant is passed through expansion valve, where it goes through isenthalpic expansion, and its temperature is reduced to very low degree. [4][7] Then, this low temperature liquid is passed through the evaporator (or to the air conditioner) where it absorbs heat and becomes saturated vapour. This vapour is absorbed by libr2 solution due to its high affinity towards it, and again forming a libr2 + h2o solution, which is pumped to the generator for the next cycle. In the airconditioning loop the chilled refrigerant is used to chill the air blowing in to the room to be air-conditioned, and this chilled air rejects its heat to the refrigerant and absorbs heat from the room. [4][7]

## Conclusion

On the whole we can assume that the future of refrigeration science is safe and secured in the hands of our scientists, engineers and researchers who are continuously working towards sustainable cooling technology. The new methods of cooling like thermo-electric effect and solar assisted refrigeration system have the potential to become basis of future technology. We expect that this brief review about the potential of solar assisted vapour absorption air conditioning system will act as a guiding beam of light for the young researchers and scholars who wish to work on the promising technology for a sustainable future.

Moreover so because the cooling requirement is directly proportional to the rise in ambient temperature, which in turn is directly proportional to the solar heat gain by the solar power circuit. Therefore we are of the firm opinion that the application of solar thermal energy is most feasible, Potential and viable in the in the field of refrigeration and air conditioning.

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# Heat Transfer Study of Binary Mixture of Group B Particles in the Gas – Solid Fluidized Bed using Acoustic field.

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## ABSTRACT

*The behavior of binary mixture of similar size and density of group B particles (Sand and Clay with mean diameter 200 µm) and the heat transfer coefficient between immersed horizontal heating tube in the gassolid fluidized bed in presence of an acoustic field was studied. Two types of data are investigated as function excess air velocity and sound pressure level for the average and local heat transfer coefficient for binary system. The experimental result showed that acoustic energy at sufficient intensity and sound pressure level improves the quality of fluidization in binary system.*

***Keyword: Fluidization, SPL, Sound wave, Heat transfer, Binary particle.***

## I. INTRODUCTION

Most of the published research on heat transfer in sound assisted fluidized bed is focused on mono component system, while there is little information available on heat transfer to multi component system. The Morse [1] found that the fluidization quality of group C particles could be improved by the application of sufficient sonic energy generated by loudspeakers located at the bottom of bed. Recently, Nowak and Hasatani [2] reported significant improvement observed in the quality of fluidization when low frequency acoustic energy of sufficient intensity was introduced,. Sound pressure level (SPL) greater than 100 dB were found to decrease in minimum fluidization velocity and increase in the heat transfer coefficient. Derezynski et al [3] studied the effect of sonic energy on fluidization and heat transfer of fine particles which belong to group C powders. Authors reported that the extent of bed expansion varies greatly raise accordingly the frequency of the sound and the highest increase in heat transfer coefficient is at low frequencies and at secured resonance. Chirone et al [4] studies the effect of acoustic field on fluidization of cohesive powders. Their observation showed that homogeneous bubble free fluidization of ultra fine particles was obtained when operated in an acoustic field with appropriate combination of bed weight, sound intensity and resonant frequency. Leu and Chen [6] used the speaker at top of the bed powered by an audio amplifier to investigate the primary effect of sound intensity on the fluidization of group B particles, and observed that the minimum fluidization velocity decreases with increase in intensity. Experimental studied of heat transfer in a fluidized bed with a horizontal tube with group B particles Grewal and Saxena [7] demonstrated that heat transfer coefficients are related to the volumetric capacity of the particles, the particle diameter and the thermal conductivity of fluidizing gas. Chandran and Chen [8] reported that local heat transfer coefficient were strong function of angular positions, particle size, system pressure and gas flow rate. Author measured steady state heat transfer coefficient for particle sizes 125 – 1580 µm by specially instrumented tube with thermocouples and heat generation from an electrical inconel foil. McKain and Atkinson [9] investigated instantaneous heat transfer coefficient values of which varies from 200 – 500 w/m2k for 250 µm Sand particle with horizontal tube. Olsson and Almsted [10] investigated the influence of excess gas velocity on the local instantaneous and time average heat transfer in a fluidized bed. The bubble caused a rapid mixing in the bed which led to high heat transfer rates between the bed and immersed surface and between the gas and particles. Author demonstrated that the correlation between the heat transfer coefficient the local bubble frequency reflected to a large extent the coupling between the frequency with which the particles near the tube surface were being placed by fresh, thermally unaffected particles. Kim et al [11] reported the effect of gas velocity on average and local heat transfer coefficient between a submerged horizontal tube and a fluidized bed heat exchanger of silica sand particles. They found that average heat transfer coefficient increases with increase in gas velocity and local heat transfer coefficient was maximum at the sides of the tube. The bubble frequency increased and emulsion contacting time decreased with increasing gas velocity. Huang and Levy [12] studied the heat transfer and bubble behavior in a sound assisted fluidized bed with horizontal tube. Author reported that bubble frequency increases with an increase in excess air velocity, the sound pressure level, the packet residence time and the fraction of the packet contact time at the tube surface decreased with increased in excess air velocity and decreased with an increased in sound pressure level. They also found that a gas film is present in the vicinity of the tube surface. The gas film increased slightly with increased excess air velocity and decreased with an increase in sound pressure level. The convective heat transfer coefficient between the tube surface and the bed material is strongly affected by the existence of the gas film between the heated surface and the emulsion phase.

In fluidized bed particle mixing, not only the particle segregation but also the temperature segregating may occurs under particular conditions. Gu and Satoh [13] experimentally examined the particle and temperature segregations in fluidized bed of binary particle mixtures. It was found that the temperature segregation results mainly from low heat transfer coefficient through the interface layers, which exists in between the floatsom and jetsom – rich layers, and that the heat transfer coefficient increases rapidly with increasing the excess gas velocity. Gu [14] further showed that the particle exchange rate of the interface layer increases with excess gas velocities, and the heat transfer coefficient which is dependent upon the volume exchange rate of the particles also increases. It was shown that the heat transfer coefficient or the thermal conductivity in the interface layer is influenced by the densities and specific heat capacities of the particles. Chongdian and Guo [15] studied the fluidization behaviors of binary mixtures of biomass and quartz sand for the investigation in an acoustic bubbling fluidized bed. Two kinds of biomass particles, sawdust and wheat stalk, were employed in this test. The experiment indicated that the addition of quartz sand can improved the fluidization quality of biomass. The minimum fluidization velocity of the mixtures increased with increasing biomass content in the mixtures. A new correlation was developed for predicting the minimum fluidization velocity of different binary mixtures. The minimum fluidization velocity decreased with increasing sound pressure level at the same sound frequency. Moreover, the minimum fluidization velocity has a maximum value over the sound frequency range of 100 – 200 Hz. Such an acoustic fluidized bed operated in a stable or unstable fluidization regime depending on the operating conditions. In this paper fluidized bed subject to acoustic field behavior of binary mixture, the particle motion in the segregated fluidized bed, heat transfer coefficients, was experimentally studied by using acoustic field with immersed horizontal heating tube, and its effect on the behavior of fluidization and heat transfer in the fluidized bed were discussed.

**Experimental:**

The experimental apparatus used for the fluidization experiments is schematically illustrated in fig. 1. It consists of fluidized bed is a 115 mm I. d. and 610 mm high Plexiglas column, with a porous polymer plate used as a gas distributor, and a horizontal heating cylinder of copper material. Experiments were performed with compressed air and the flow rate was monitoring by a rotameter (Eureka of uncertainly 3 % of full scale reading). The bed materials used were group B binary mixture of Sand and Clay with mean size of 200 μm in all experiments.

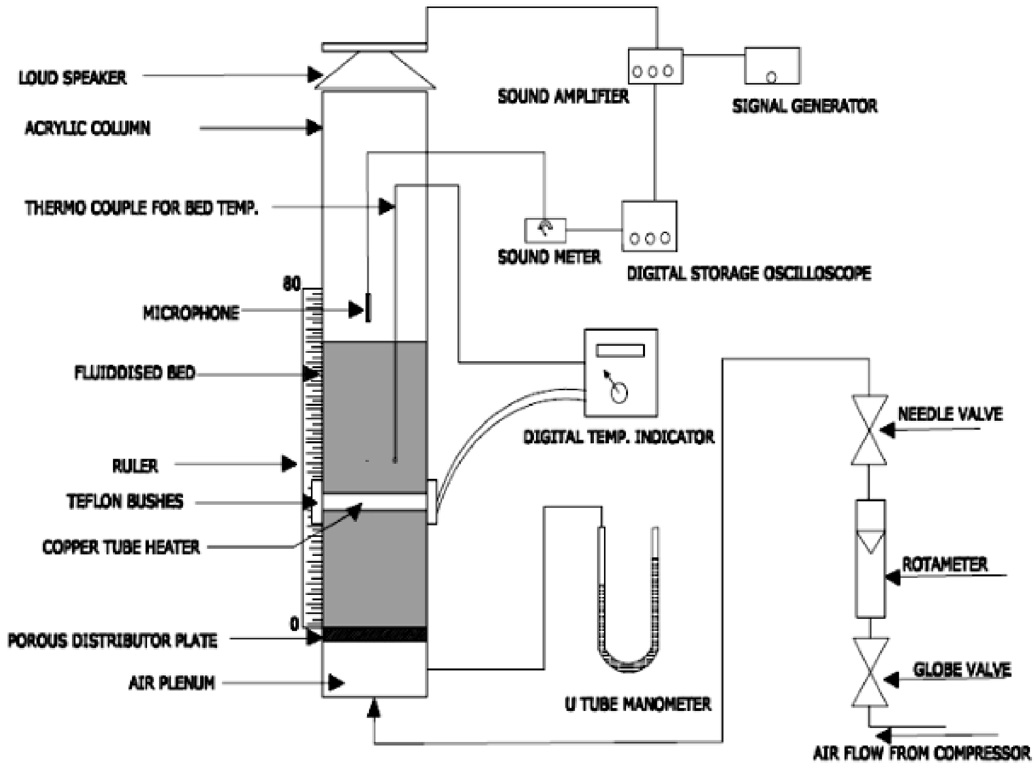


**Figure 1:** Schematic diagram of the experimental set up of sound assisted fluidized bed system.

In 8" diameter loud speaker (4 Ω impedance) installed at the top of the fluidized bed column was used to generate sound as the source of the acoustic field. A signal generator was used to obtain a sine wave signal, which was amplified by a 50 W amplifier. The sound pressure level (SPL) was measured just above the free surface of the fluidized bed using sound measuring system is connected with microphone (Bruel and Kjaer – model 4944). The sound pressure level (SPL) is commonly defined by [16]

Where  is the effective sound pressure level and  1 is the reference sound pressure, which are obtained by the sound measuring system.

A heating cylindrical element of 25 mm i. d. was installed horizontally through the center of the bed at 80 mm above the distributor, and extended on two sides by Teflon bushes to minimized heat losses, used to determine the heat transfer coefficient. Four K – type wire thermocouples were fixed in grooves made on the heater tube at 900 intervals to measures the surface temperature and bed temperature was measured with K – type wire thermocouple placed parallel to the heater tube at radial distance of 2.5 cm from the center of the bed as shown in fig. 2.

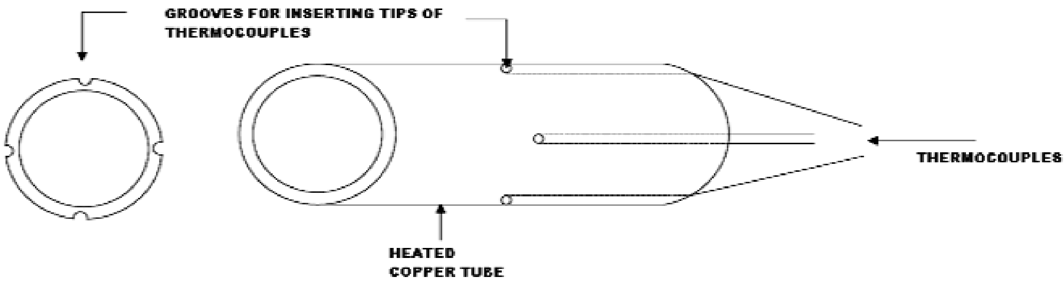


**Figure 2:** Layout of configurations of the heated tube. Heat transfer coefficient were obtained from equation, where, 2 is the convective heat transfer coefficient (w/m2k), I is the current (amperes), R is the resistance (Ω), is the surface area of the element, the surface temperature (k) and Result and discussion: is the bed temperature (k). is

The heated tube was tested for the heat transfer measurement at specific sound pressure level (SPL) and acoustic frequency in a fluidized bed of binary mixture of group B particles Sand and Clay with mean particle diameter 200 µm. Addition of assisting particles like Sand 200 µm to an acoustic fluidized bed increases the fluidization. The mixing of binary system at the beginning of a fluidization experiments can be charged into the column in different ways i.e. well mixed assembly of particles and two completely segregated layers of each component behaves like a fixed-bed arrangement reported by Formisani et al. (17).

Fig. (3) shows the plot of local heat transfer coefficient (hlocal) for the mixture of group B particles at different locations of heated tube along the circumference at 90 Hz and at twice the velocity of umf. The local heat transfer coefficient increases from 120 dB to 140 dB. However, the local heat transfer coefficient decreases after 140 dB. The fluidization behavior of particles is significantly affected by acoustic field and hence there is a major effect on local heat transfer coefficient Nowak et al (2). An increase in gas velocity in absence of sound intensity, voidage in the bed increases with rise in bed height. Due to increases in bed voidage particle to particle and particle to surface contact is minimal and thus the heat transfer coefficient is observed less value than the acoustic fluidization heat transfer. The effect of increased in gas velocity shown in figure (4). The bubble increased with increasing gas velocity that led to increase in local heat transfer coefficient is reported by Kim et al (11). Maximum local heat transfer coefficient observed shown in figure (3) at sides of the wall θ = 2700 directly affect by both bubble motion with sliding motions of solids as reported by Sundersan (18), Kim et al (11).

In the top region of the heated tube θ = 1800,hlocal, attained low values since solid particles reside for longer on the top of the tube with low bubble frequencies. In the bottom region of the heated tube θ = 00, hlocal, exhibits higher value compare to θ = 1800. Vigorous bubbling occurs at bottom of the heated tube having high frequency since solid particles resides short time in spite of low emulsion fraction or solid holds up (11). However, with increased in sound pressure level (SPL) more than 140 SPL, voidage decreases markedly, the packets do not get sufficient contact time to carry from heated wall and as an effect, hlocal, reduces.

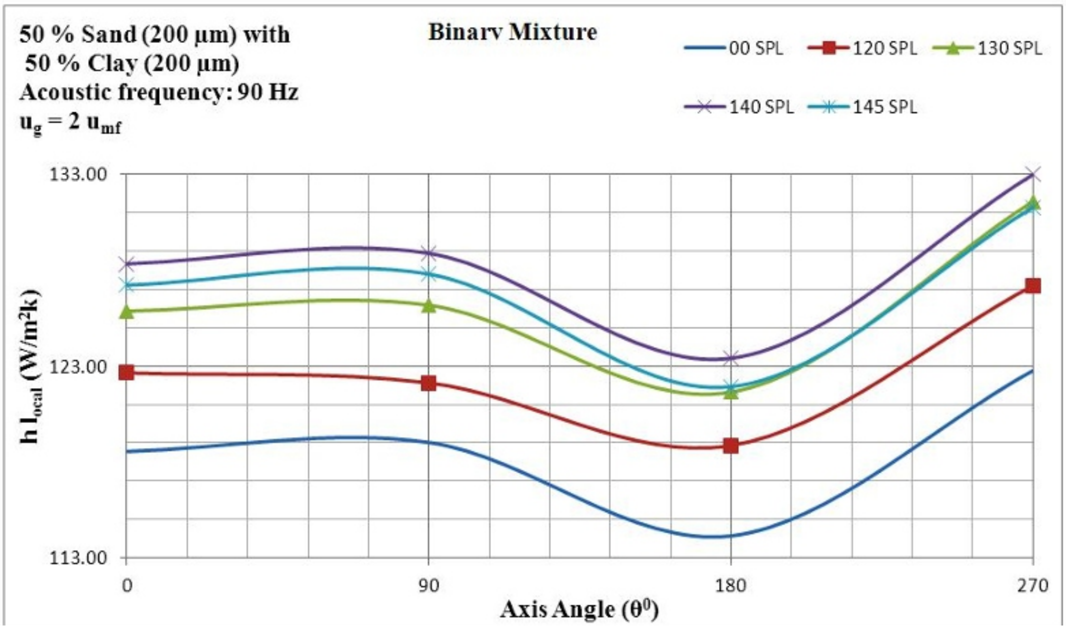


**Fig.** (3): Effect of SPL on the local heat transfer coefficient.

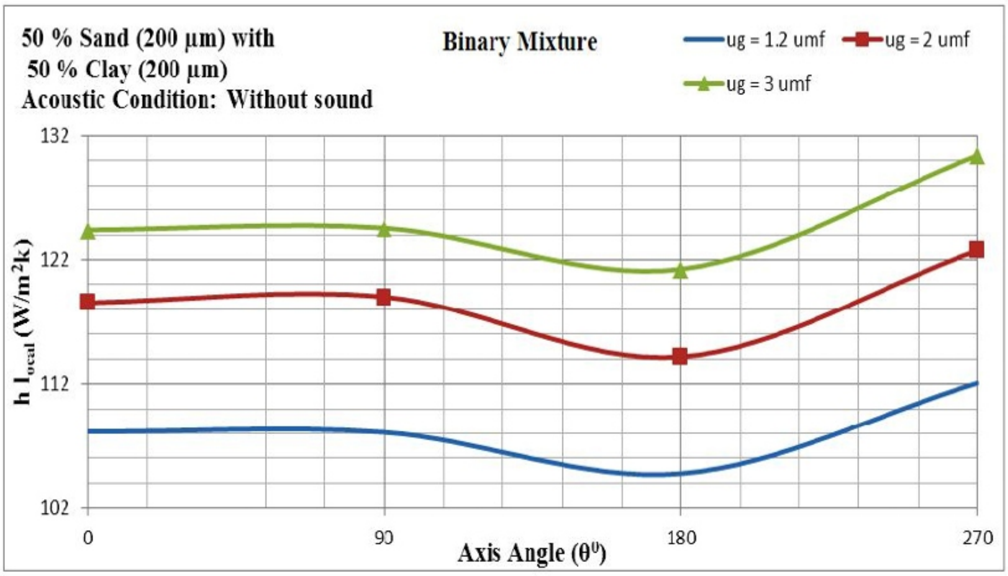


**Fig. (4):** Effect of ug on the local heat transfer coefficient at without acoustic condition.

The relationship between SPL and the average heat transfer coefficient (havg) is shown in figure 5 for binary mixture of group B particles. As can seen, havg, increases with an increase in SPL upto 140 dB leads to increase in replacement rate of solid packets and solid mixing in the bed. Thefluidization behavior of binary mixture particles is significantly affected by acoustic field and hence increases in average heat transfer coefficient.

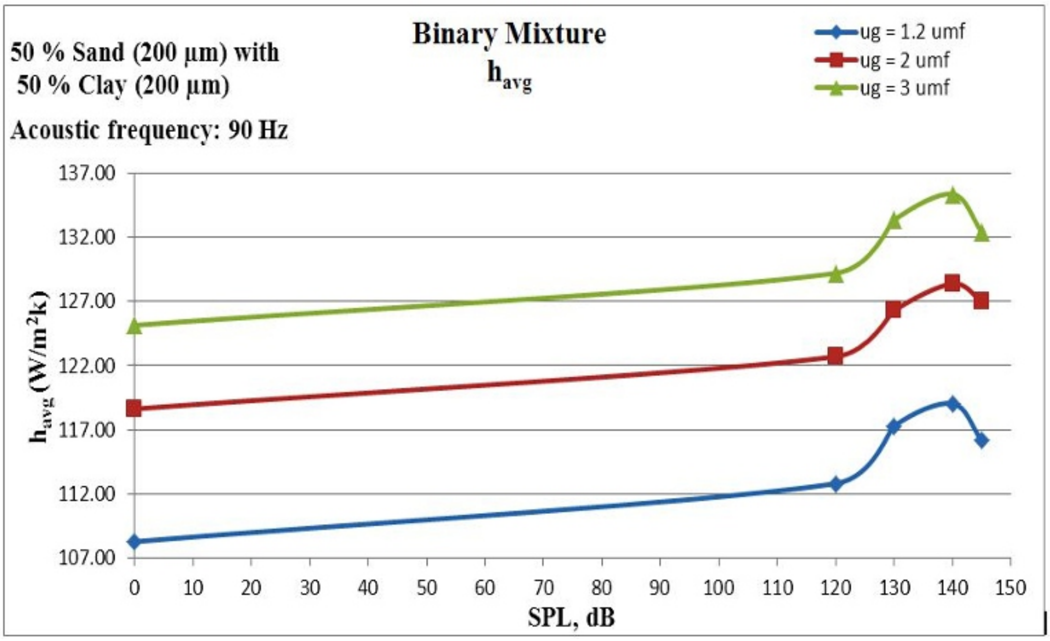


**Fig. (5):** Effect of SPL and ug on the average heat transfer coefficient.

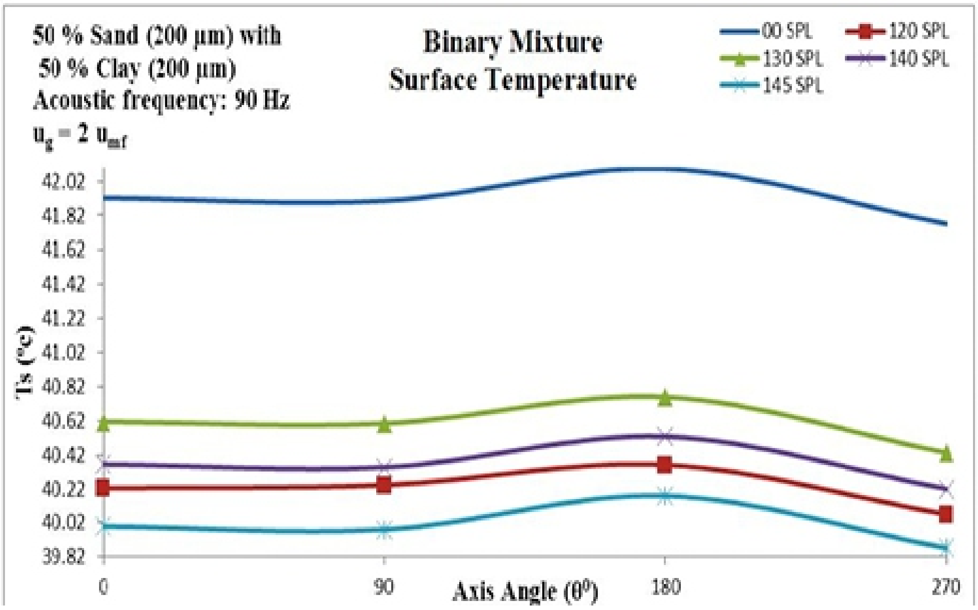


**Fig. (6):** Effect of SPL on the behavior of temperature variation along the circumference of the heated tube.

The variation of surface temperature values can be recorded in fig. (6) with angular positions along the circumference of the heated tube binary mixture. The heat transfer rate of the heated tube is governed by the frequency of deterioration of the stagnation zone and the fresh particle packets extract heat from heated tube and replacing the older hotter particles. At θ = 1800 indicates the lack of temperature variation sensed by thermocouple. This is due to a stagnation zone is located on the top surface of the heated tube. Thermal activity rate is highest at the sides of heated tube θ = 900 and θ = 2700 due to continual replacement of fresh particle packets and is slightly lower at the bottom surface θ = 00. The scenario of temperature variations with angular position along the circumference of the heated tube is shown in fig. (6) at different sound pressure level.

The field of heat conduction has been of great interest to researchers, since the fluidized bed is characterized by high heat conductivity. Mixing of particles and the frequency of sand particle collisions increases, which enhances more intensive diffusion of heat and thus increases the heat transfer coefficient of the fluidized bed.The thermal conductivity of the fluidizing sand (200 μm) is more as compare to clay (200 μm) that increases, hlocal, with increased in SPL upto 140 dB.

**Conclusion:**

The experimental result indicates that acoustic field can improve the fluidization quality of mixture. The fluidization behavior of binary mixture of particles at the same size and same density is strongly influence by the thermal conductivity of the fluidizing Sand. The heat transfer data showed that the average heat transfer coefficient increased with increasing gas velocity. It also found that as sound pressure level of acoustic field increases, local heat transfer coefficient increases.

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# Technological Review of the Geothermal Energy Systems from Indian Perspective

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## A B S T R A C T

*Geothermal Power is one of the fastest growing sources of renewable energy in the world and even in India. With an estimated potential of over 10000 MW India is having a large resource available to be harnessed. Out of the available energy resources geothermal energy has a distinct advantage of being a base load power plant capacity. Technology overview of geothermal energy from its evolution to the current advanced systems of geothermal technology has been discussed in this paper with a view to make the readers and young researchers acquainted with this green source of energy, i.e. Geothermal energy.*

***Keywords: Geothermal, Renewable, Energy, Technology.***

### I. INTRODUCTION

Geothermal" literally means earth heat energy involves using the high temperatures produced beneath the earth to generate electricity from heated water, as well as for various direct uses like hot springs spas, lumber drying or aquaculture. Therefore geothermal energy means the thermal energy stored beneath the surface of the earth crust. The term geothermal is also applied to the temperatures of the Earth near the surface which are used as a source of consistent temperatures for heating and cooling of buildings. Geothermal applications that involve water heated within the earth are also called hydrothermal processes. 1

Geothermal Power is one of the fast growing renewable energy source in the world and even in India. With a potential of over 10000 MW India is having a huge resource available and waiting to be harnessed. As demand of energy is growing at an exponential rate, the world is bound to move towards renewable energy resources. Out of the available energy resources geothermal energy has a distinct advantage of being a base load power plant capacity, i.e. it can be used as a base load plant for 24 hour power production as other conventional power plants.

In the countries like Unite States of America and Philippines, importance and potential of geothermal energy has been realised and they are moving ahead towards sustainability with the geothermal power as an alternative source of energy. Technology overview of geothermal energy from its evolution to the current advanced systems of geothermal technology has been discussed and presented in this paper with a view to make the reader and young researchers acquainted with this green source of energy, namely Geothermal energy.

Genesis of Geothermal Technology

The heat from the earth's own molten core is conducted to the adjacent rocks through conduction and convection and eventually is transferred to underground water reservoirs through conduction and convection. Steam/water heated by the geothermal heat can be tapped using different technologies and channelled to various uses.

Utilization of geothermal fluid depends heavily on its thermodynamic characteristics. These factors are determined by the geothermal system from which the fluid originated.

Geothermal heat is constantly produced by the Earth from the decay of radioactive material in the core of the planet. The heat is moved to the surface through conduction and convection. In the crust, the temperature gradient is typically 30°C per kilometre but can be as high as 150°C per kilometre in hot geothermal areas. If even a small fraction of the Earth"s heat could be delivered to the points of energy demand by humans, the energy supply problem would be solved. The global technical potential of the resource is huge and practically inexhaustible. However, tapping into this tremendous renewable energy reservoir is not an easy task. 2 Geothermal fluids have been classified differently by different researchers; some have done so by using temperatures while others have used enthalpy. Depending on the enthalpy/ temperature of the geothermal fluid, it can be utilized either for electricity generation or direct applications. Electricity generation is the most important form of utilization of high-temperature geothermal resources while low to medium temperature resources are better suited for direct application.

**Table 1:** Types and Uses of Geothermal Resources

| **Resource Availability** | **Geographical And Geological Location** | **Use / Technology** |
|---|---|---|
| High: > 200°C | Globally around boundaries of tectonic plates, on hot spots and volcanic areas. | Power generation with conventional steam, flash, double flash, or dry steam technology. |
| Medium: 150-200°C | Globally mainly in sedimentary geology or adjacent to high temperature resources. | Power generation with binary power plants, e.g., ORC or Kalina technology. |
| Low: < 150°C | Exist in most countries (average temperature gradient of 30$^{o}$C/km). | Direct uses and depending on location and power tariff offered, power generation with binary power plant |

(Source: Gehringer, M., Loksha, V., Geothermal handbook: Planning and financing power Generation, ESMAP World Bank, 2012)

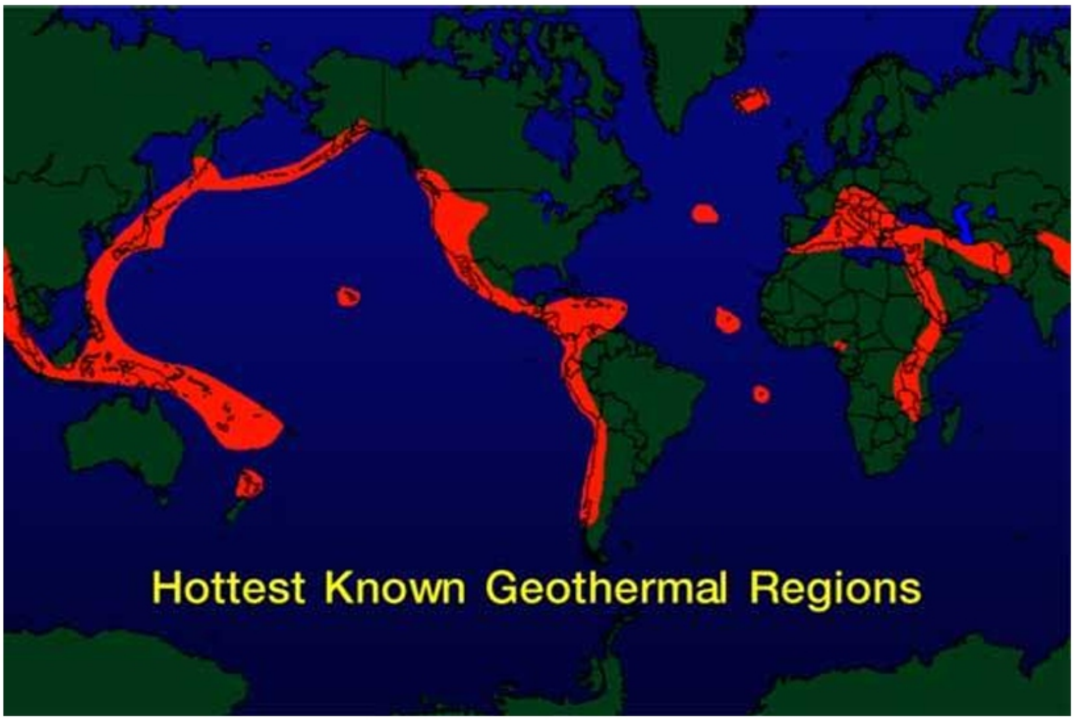


**Figure 1:** Ring of Fire

(Source: http://www.greenibis.com/edu/geo/frames/where.html)

Humans have been utilizing this geothermal energy ever since pre historic era. Up until a century ago, geothermal energy was known mostly as a source of heat for spa and bathing purposes. The use of geothermal steam for electricity production began in the 20th century-with the first experimental installation built in Larderello, Tuscany, Italy in 1904 2. Ever since then there has been a great improvement in technology for harnessing geothermal energy, either for producing electricity or for any other process heating / cooling application. A 250 kWe geothermal power plant began operation there in 1913. 2 Geothermal features are not common geological features. They occur in clusters, in a few widely separated locations of the world where the conditions are right for their occurrence.

We can find some of the most active geothermal zones of the world around "Ring of Fire" are as: Yellowstone (USA), North Island (New Zealand), Iceland, Kamchatka (Russia), and Japan.3

Like any other energy resources in the world, geothermal energy has its own set of advantages and disadvantages, some of these merits / challenges are enumerated as follows 2:-

**Table 2:** Merits and Challenges of Geothermal Resources

| Advantage / Merit | Disadvantage/Challenge |
|---|---|
| Globally inexhaustible (renewable) | Resource depletion can happen at individual reservoir level |
| Low/negligible emission of CO2 and local air pollutants | Hydrogen sulphide ($H_2S$) and even $CO_2$ content is high in some reservoirs |
| Low requirement for land | Land or right-of-way issues may arise for access roads and transmission lines |
| No exposure to fuel price volatility or need to import fuel | Geothermal "fuel" is non-tradable and location constrained |
| Stable base-load energy (no intermittency) | Limited ability of geothermal plant to follow load/respond to demand |
| Relatively low cost per kWh | High resource risk, high investment cost, and long project development cycle |
| Proven/mature technology | Geothermal steam fields require sophisticated maintenance |
| Scalable to utility size without taking up much land/space | Extensive drillings are required for a large geothermal plant |

Some of the major highlights of a geothermal energy systems as observed by the author Gehringer, M. and Loksha, V. in their book "Geothermal handbook: Planning and financing power Generation" published by ESMAP World Bank in the year 2012 are listed below 2:-

i. Geothermal fields are generally found around volcanically active areas that are often located close to the boundaries of tectonic plates. Nearly 40 countries worldwide possess sufficient geothermal potential that could, from a technical perspective, satisfy their entire electricity demand with geothermal power.

ii. Electricity from geothermal energy is produced by 24 countries. The United States and the Philippines have the largest installed capacity of geothermal power, about 3,000 MW and 1,900 MW, respectively. Iceland and El Salvador generate as much as 25 percent of their electric power from geothermal resources.

iii. Geothermal power generation from hydrothermal resources can be expected to grow from 11 GW in 2010 to 17.5 GW by 2020 and to about 25 GW by 2030. Most of this increase is expected to happen in Pacific Asia, mainly Indonesia; the East-African Rift Valley; Central and South America; as well as in the United States, Japan, New Zealand, and Iceland.

iv. Geothermal is a commercially proven renewable form of energy that can provide relatively cheap, low carbon, base-load power and heat, reducing a country"s dependence on fossil fuels and CO2 emissions.

v. The development of geothermal power generation cannot be regarded as a quick fix for any country"s power supply problems, but should rather be part of a long term electricity generation supply strategy.

vi. Geothermal power projects are best developed in steps of 30 MW to 60 MW in order to reduce concentration of resource risk and to minimize the risk of unsustainable exploitation of the geothermal reservoir.

vii. Investment costs per installed megawatt can vary widely, from US$ 2.8 million to US$ 5.5 million per MW installed for a 50 MW plant, depending on factors such as the geology of a country or region, quality of the resource (e.g., temperature, flow rate, chemistry), and the infrastructure in place.

viii. Despite its high upfront costs, geothermal power can be competitive and complement other sources of generation thanks to high capacity factors, long plant lifetimes, and the absence of recurring fuel costs.

ix. Levelized costs of energy from hydrothermal resources are usually found to be between US$ 0.04 and 0.10 per kWh.

Based on the above observations we can clearly deduce the fact that geothermal energy is available in abundance in the world, but its extraction needs focus of the global community to propagate this renewable source of energy.

## INDIAN GEOTHERMAL POTENTIAL

India has a good potential for geothermal resources and all the geothermal zones of India are located in areas with high heat flow and geothermal gradients. The heat flow and thermal gradient values in India varies from 75-468 m W/m2 and 59-234°C respectively. The estimated power generating capacity of the geothermal energy is about 10,600 MW. 15

The seven major geothermal provinces of India, as shown in figure 2, which encloses nearly 400 thermal springs, are in the region associated with the mid continental rifts, subduction, sedimentary basins and Cretaceous-Tertiary volcanic zone.These provinces include: 15

I) The Himalayas,

ii) Sohana,

iii) Cambay,

iv) Son-Narmada-Tapi rift zone (SONATA),

v) West coast,

vi) Godavari, and

vii) Mahanadi.

In the recent event of last decade the volcanic eruption in the Barren islands has become one the most important geothermal provinces in the Indian subcontinent. The estimated energy from one third of these springs is of the order of 40.9x1018 calories.

This is equivalent to the energy that can be obtained from 5.7 billion tons of coal or 28 million barrels of oil. If these energy resources are developed for a medium to low temperature application it will substitute about 10,600 MW of power. 15

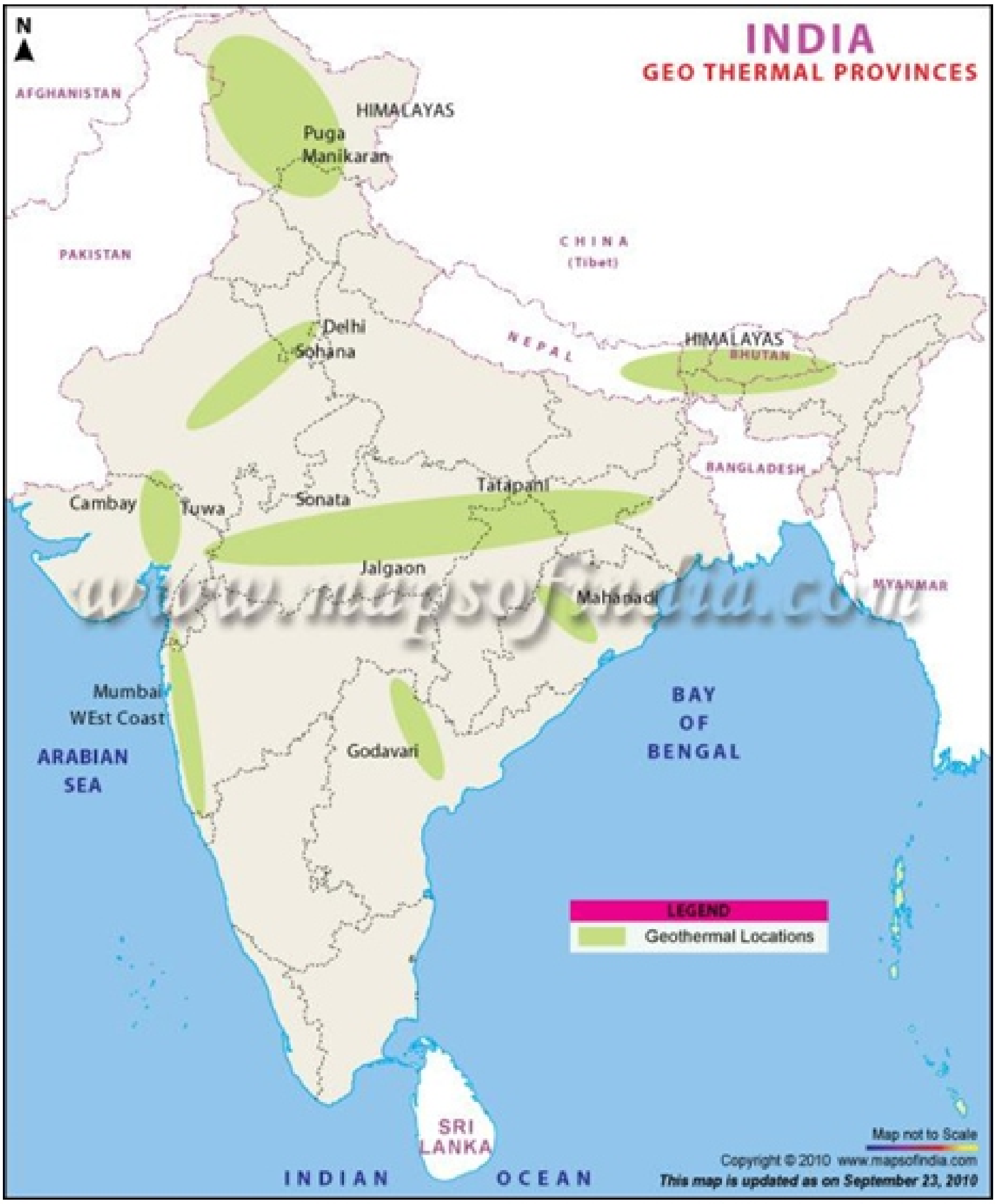


**Figure 2:** Geothermal Potential Map of India[15]

(Source: http://www.mapsofindia.com/maps/nonconventional/geothermal.htm#)

**Classification of Geothermal Technology**

In order to extract geothermal heat from the earth, water is used as the working medium. Generally the naturally occurring groundwater is available for this task in most places but more recently technologies are being developed to even extract the energy from hot dry rock resources. The underground temperature of the resource is a major determining factor of the technologies required to extract and utilize the available thermal energy. The Table 3 given below enlists the basic technologies normally used in accordance to the available resource temperature. Energy conversion technology for geothermal applications can be broadly classified into three types, as given below:

• Dry steam power plants

• Condensing power plants

• Binary plants.

**Table 3:** Basic Technology Commonly Used For Geothermal Energy

| **Reservoir temperature** | **Working Fluid** | **Technology commonly chosen** | **Application** |
|---|---|---|---|
| High temperature, > 220°C | Dry Steam | **Dry steam plant** | Power generation, Heat exchangers, Heat pumps |
| Intermediate temperature 100-220°C | Hot Water or Steam | **Flash Steam Plant** | Power generation, Heat exchangers, Heat pumps |
| Low temperature 30-150°C | Hot Water | **Binary fluid plant** | Power generation, Heat exchangers Heat pumps |

(Source: Martha, M., Geothermal Energy Utilisation, Short Course IV on Exploration for Geothermal Resources, Kenya, 2009)

On the whole we could say that the geothermal power generation has the following positive features:

- Lower emission of CO2, which is a main source of global warming
- Higher availability factor
- Use of more sustainable energy

But due to the variable steam conditions at source and larger equipment size, geothermal power generation tends to involve higher capital costs per output compared with fuel-fired power systems. We need to plan to improve the economic efficiency by improving turbine efficiency and increasing unit capacity. We will have to continue to extend efforts for the further deployment of geothermal power technology, which is an effective option to mitigate global warming, through the continuous development of anticorrosion technology to increase equipment reliability.6

**Basic Geothermal Power Cycle Technology**

Geothermal energy is the heat energy stored beneath the surface of the earth. Wherever there is heat then always there is thermodynamics involved in it to extract or harness the heat energy. So in order to harness the thermal energy of the earth we need to understand the technology and the thermodynamics involved in it. Heat is the energy transferred between a system and its surroundings due to a temperature

difference that exists between them, from a body at higher temperature to a body at lower temperature.
The Zeroth law of thermodynamics states that if two bodies, independently, are in a thermal equilibrium with a third body, then both of them must be in thermal equilibrium with each other. In the case of geothermal energy, this can be used to explain the process of the vaporization of the working fluid / refrigerant. The water and the refrigerant are not in thermal equilibrium initially, so anything in contact with them will be at a different temperature. The heat will flow from the hot water carrying heat from the geothermal reservoir up to the / turbine or any refrigerant until those two bodies are in thermal equilibrium.
Similarly the First law of thermodynamics could be applied to the geothermal energy, as the law states that the internal energy of a system will increase if heat is added and decrease if work is done by the system, i.e. this law depicts the law of conservation of the internal energy of a system. In the case of geothermal energy, heat is added to the system of the refrigerant and turbine by the temperature difference between the refrigerant and the water. If heat is added, the internal energy of the system must either increase, or be offset by the work being done in the form of electricity by the turbine or in the form of direct application of heat in any process. Thus the energy is conserved as per the first law of thermodynamics.

According to the Second law of thermodynamics, for any process in a closed system, the entropy never decreases. In the case of geothermal energy, we can assume that the system between the ground, the mixing chamber, and the turbine is a closed system. This can be assumed because the process of pumping up the water and returning it to the earth requires a fair amount of energy that cannot be regained. Since, it is clear that the first three laws of thermodynamics can be applied to the geothermal process, so now it is also relevant to know the efficiency of this system. Efficiency is the ratio of input to output, a performance measure for the process. The thermal efficiency is seen as the ratio of produced power to the heat transferred to the power plant. The power plant thermal efficiency is the ratio between power produced and the heat flow to the power plant. The heat input is then the heat input to the power plant, and takes no notice of how much heat is available from the wells. The power plant thermal efficiency is traditionally defined as:[16]
*Efficiency = [Power produced / Heat supplied to the power plant]
***Thermal Efficiency ($\dot{\eta}$)** = [W / Q]
*Where,
W-Power / work produced by the power plant
Q-Heat energy supplied to the power plant.
*Source:http://ffden
2.phys.uaf.edu/212_fall2009.web/Nathan_Burke.dir/contentpage4.html

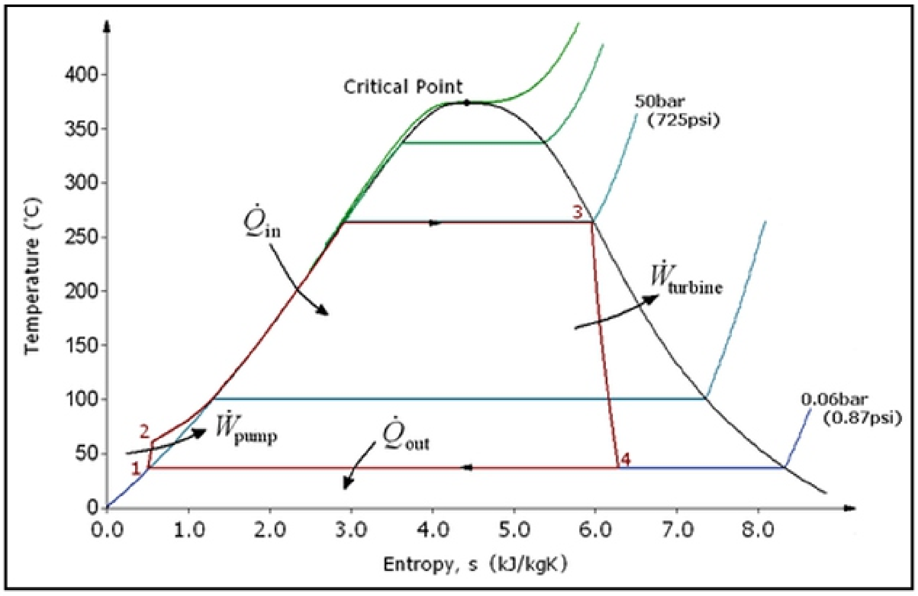


**Figure 3:** T-S diagram of typical Rankine cycle

Source: http://en.wikipedia.org/wiki/Rankine_cycle

## Conclusion

Geothermal energy is a vast source of energy available beneath the earth crust, ready to be harnessed. Geothermal energy has gone through a lot of evolution from the naive thermal application to the complex technology for power production. Though this power is dependent on the geographic features and lithosphere composition of the region, but wherever it is available there it can be a good source of power if harnessed properly with the aid of right kind of technology. If energy prices continue to rise, direct use of geothermal resources could provide an economical, clean and renewable source of thermal energy. We have learnt that one of the most efficient modes of energy conversion for indirect use of geothermal energy is through dry steam power plant. But this power plant requires dry steam at high temperatures, which is unfortunately not available easily. Therefore this technology is limited to only those geothermal sites where high potential thermal energy is available at our disposal.

With the available technology we are not able to harness this energy potential of earth to the fullest. But sooner or later we will need to develop those customized and efficient technologies which are able to extract maximum energy from the deep surfaces of the earth.

India"s ambitious energy program focuses on proliferation and propagation of its Renewable Energy Sources. The Policy makers hope that India will be generating substantial quantity of power through these green sources in future. If the geothermal energy potential is exploited to the fullest then India can have self sustainability in electricity production. In the very near future India may appear on the map of the world with the proposal of generating power and direct utilization of geothermal energy from the existing bore wells. We can conclude by observing that geothermal energy has a lot of potential to develop into sustainable and clean sourceof energy, all it needs is the collaborative efforts of the entire human community, especially in rural India.

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# Exact Solution for Transient Heat Conduction through Long Fin

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## ABSTRACT

*This work emphasizes on the analysis of transient heat conduction through fins. The exact local and mean temperature distribution had been generated by numerical technique methods. Exact solutions are given for the transient temperature influx-base fins with the method of Green's functions (GF)in the form of infinite series for three different tip conditions. The time of convergence is improved by replacing the series part. For the long fin case, exact fin solution is presented in graphical forms. Programmed solutions are determined for analysis of exact fin theory. Dimensionless temperature distribution is also presented for exact fin theory.*

***Keywords: Fin, Transient Conduction, Extended Surface, Exact Solution***

**Nomenclatures**

| | |
|---|---|
| Ah | surface area of fin for convection (m2) |
| α | thermal diffusivity (m2s-1) |
| Bi | Biot number, hi (V/Ah)/K |
| βn | eigen value [eq. (1)] |
| B2 | Biot number, hL/k |
| θ | dimensionless temperature |
| G | Green's function |
| ξ, X | dimensionless x-coordinate |
| h | heat transfer coefficient (W m-2K-1) |
| τ, dt | dimensionless time |
| k | thermal conductivity (W $m^{-1}K^{-1}$) |
| L | length of fin (m) |
| $N_n$ | norm [eq. (1)] (m) |
| m | fin parameter, ($m^{-1}$) |
| M | dimensionless fin parameter = mL |
| $q_o$ | heat flux (W $m^{-2}$) |
| Q | input heat (W) |

| | |
|---|---|
| T | temperature (K) |
| t | time (s) |
| V | fin volume ($m^3$) |

## 1. Introduction

Fins are the extended surfaces used for enhancing the dissipation of heat transfer rate. The transient response of fins is important in a wide range of engineering devices, automobiles and industrial sectors. Work under steady state conduction had been carried out extensively. Transient heat conduction analysis for the fins is being considered for simplifying heat transfer queries. Transient Closed form solutions had been derived earlier by various researchers.

Chapman [1] studied the transient behavior of an annular fin of uniform thickness subjected to a sudden step change in the base temperature. Donald son and Shouman[2] studied the transient temperature distribution in a con vecting straight fin of constant are a for two distinct cases, namely, a step changeinbasetemperature, and a step change in base heat flow rate.Suryanarayana[3,4] studied the transientresponse of straight fins of constant cross-sectionalarea. However, rather than using the separation of variablestechnique followed by [2],Mao and Rooke[5] used the Laplace transform methodtostudy straight fins with three different transients: a step changein base temperature; a step changein baseheat flux and a step change in fluid temperature. Transientfinsof constant cross-section have also been studied with the method of Green's functions [6], a flexibleandpowerfulapproach that areapplicabletoany combination of end conditions on the fin. Kim [7] developedan approximate solution to the transientheat transferin straight finsof constantcross-sectional areaandconstantphysical andthermal properties. Aziz and Na [8]consideredthe transient responseofa semi-infinite fin of uniformthickness, initially at the ambienttemperature, subjected to a step change in temperature at its transient base,with fincooling governed by a power-law type dependence on temperature difference.Aziz and Kraus [9]presenta variety of analytical results for fins, developedseparation of variable and Laplacetransformtechniques. by Campo and Salazar [10] explored the analogy between the transient conduction in a planar slabfor short times andthe steadystateconduction in a straight fin ofuniform cross-section. Saha andAcharya[11]given adetailed parametricanalysisof the unsteadythree-dimensional flow and heat transfer in a pin-fin heat exchanger. Several numerical studies oftransient fins combined with complicating factors,such as natural convection [12, 13], spatial arrays of fins [14, 15] and phase change materials [16] have been presented.Mutlu and AlShemmeri[17]studied alongitudinalarray of straight fins suddenly heated at the base. Theinstantaneousheattransfer coefficientwas found at one point on the fin as a ratio of the measured temperature tothemeasure heat flux.

Present article deals with exact temperature distribution of transient heat conduction through fins.

## 2. Governing Equations for Transient Conduction of Fins

Efficient solutions for the transient heat transfer in flux-base long fins are presented for the three different tip conditions and improvement of convergence of the series solutions. Representation of dimensionless exact fin solution for long fin is also given.

General expression for the transient heat transfer through flux base fins for the three different tip conditions is given by[18].

$$T(x,t)-T_e = \frac{q_0 L}{k}\frac{L}{N_0}\frac{\left(1-e^{-m^2\alpha t}\right)}{m^2L^2}+\frac{q_0 L}{k}\sum_{n=1}^{\infty}\frac{L}{N_n}\frac{cos(\beta_n x/L)}{m^2L^2+\beta_n^2}\times\left[1-exp[-(m^2L^2+\beta_n^2)\alpha t/L^2]\right] \quad (1)$$

Table 1shows the Eigen values for three different tip conditions.

**Table 1**.Eigen values for three different tip conditions

| ***Case*** | $\frac{L}{N_n}$ | $\beta_n$ ***Or Eigen condition*** |
|---|---|---|
| $X21$ | $2$ | $(n-{}^1\!/_2)\pi$ |
| $X22$ | $2; n \neq 0$<br>$1; n=0$ | $n\pi$ |
| $X23$ | $\frac{2(\beta_n^2+B_2^2)}{(\beta_n^2+B_2^2+B_2)}$ | $\beta_n tan(\beta_n)=B_2$ |

For the temperature-end condition,

$$\mathrm{T(x,\ t)} - T_e = 2\frac{q_0 L}{k}\sum_{n=1}^{\infty}\frac{cos(\beta_n x/L)}{m^2L^2+\beta_n^2}\times\left[1-exp[-(m^2L^2+\beta_n^2)\alpha t/L^2]\right] \quad (2)$$

Where $\beta_n = (n-1/2)\pi$

For the insulated end condition,

$$\mathrm{T(x,\ t)} - T_e = \frac{q_0 L}{k}\frac{\left(1-e^{-m^2\alpha t}\right)}{m^2L^2} + 2\frac{q_0 L}{k}\sum_{n=1}^{\infty}\frac{cos(\beta_n x/L)}{m^2L^2+\beta_n^2}\times\left[1-exp[-(m^2L^2+\beta_n^2)\alpha t/L^2]\right] \quad (3)$$

Where $\beta_n = n\pi$

For convective end condition,

$$\mathrm{T(x,\ t)} - T_e = 2\frac{q_0 L}{k}\sum_{n=1}^{\infty}\left(\frac{\beta_n^2+B_2^2}{\beta_n^2+B_2^2+B_2}\right)\frac{cos(\beta_n x/L)}{m^2L^2+\beta_n^2}\times\left[1-exp[-(m^2L^2+\beta_n^2)\alpha t/L^2]\right] \quad (4)$$

Where $\beta$ satisfies $\beta_n tan\beta_n = B_2$& $B_2 = h_2L/k$.

$$T(x,t) - T_e = \frac{q_0 L}{k} \frac{\left(\frac{mL-B_2}{mL+B_2} e^{-m(2L-x)} + e^{-mx}\right)}{mL\left(1 - \frac{mL-B_2}{mL+B_2} e^{-2mL}\right)} - 2 \frac{q_0 L}{k} \sum_{n=1}^{\infty} \frac{\cos\left(\frac{\beta_n x}{L}\right)}{m^2 L^2 + \beta_n^2} \left(\frac{\beta_n^2 + B_2^2}{\beta_n^2 + B_2^2 + B_2}\right)$$

$$(10) \times \left[exp[-(m^2 L^2 + \beta_n^2)\alpha t / L^2]\right]$$

Where β satisfies βntanβn = B2& B2 = h2L/k

It is instructive to examine above three temperature solutions as a group, contains a steady termanda transient series term. However, the insulated-tip solution uniquely contains an additional a non-series transient term.

**Dimensionless Exact Fin Solution for Long Fin**

The exact temperature expression for long fincasecontains twoterms: aseries steady term anda series transient term. Theseriescontainsanexponential factor with argumentm2L2+βn

**2.By comparing these arguments, it is clear**

thatastimeincreases the seriestermwill The numerical results are presented with the following dimensionless variables:

$$\theta = \frac{T - T_e}{q_0 L / k} \xi = X = x/L \tau = dt = \alpha t / L^2 M = \sqrt{Bi}\left(\frac{L}{V/A_h}\right) Bi = \frac{h(V/A_h)}{k} \qquad (11)$$

Where

θ = dimensionless temperature

ξ = dimensionless location

τ = dimensionless time

M = fin parameter

Bi = biot number

The dimensionless exact fin temperature for long fin is given by:

$$\theta = 2 \sum_{n=1}^{\infty} \frac{\cos\,(n - \frac{1}{2})\pi\xi}{M^2 + (n - \frac{1}{2})^2 \pi^2} \times \left[1 - exp[-(M^2 + (n - 1/2)^2 \pi^2)\tau]\right] \qquad (12)$$

**3. Result and Discussions**

Graphical results for the exact fin theory are as follows.Fig.3.1 to 3.3 shows the temperature distribution curve for exact fin theory, taking M = 0.2 & τ = 0, 0.5 & 1. Curve does not change much for large dimensionless time when M is small. Temperature decreases when location changes from zero to one.

Base temperature increases as the time increases.

Fig 3.4 to 3.6 shows the temperature distribution curve for exact fin theory, taking M = 1 & $\tau$ = 0, 0.5 & 1. Curve shows that the base temperature increases with increase in time. For low value of M temperature distribution curve remains same.

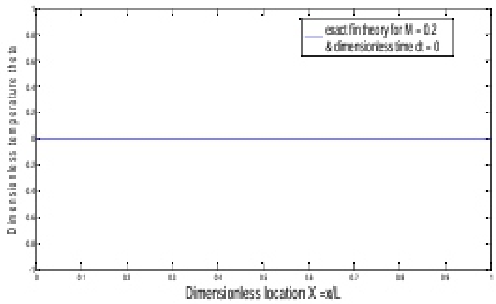


Fig.3.1 Temperature history of exact fin theory for M = 0.2 & dimensionless time dt = 0

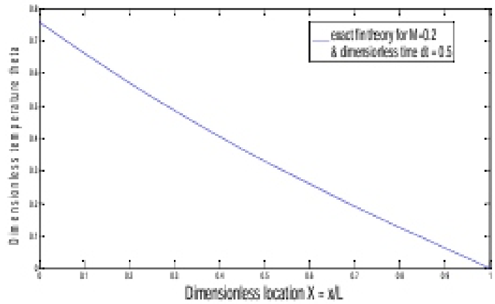


Fig.3.2 Temperature history of exact fin theory for M = 0.2 & dimensionless time dt = 0.5

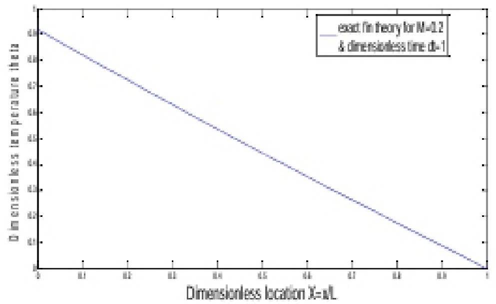


Fig.3.3 Temperature history of exact fin theory for M = 0.2 & dimensionless time dt = 1

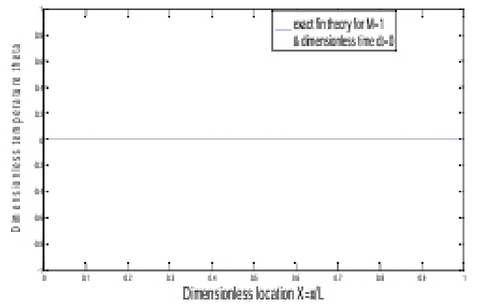


Fig.3.4 Temperature history of exact fin theory for M = 1 & dimensionless time dt = 0

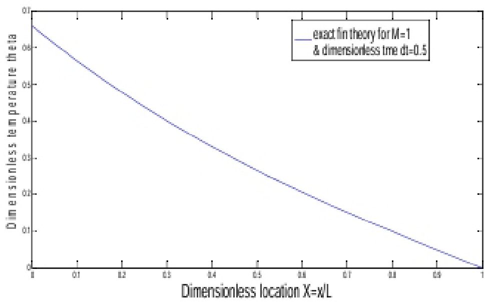


Fig.3.5 Temperature history of exact fin theory for M = 1 & dimensionless time dt = 0.5

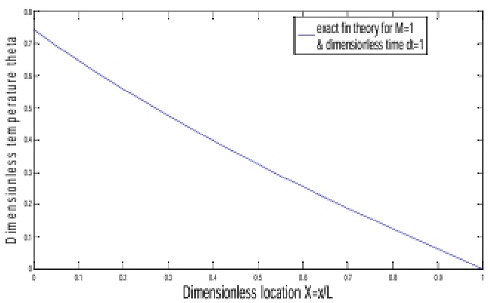


Fig.3.6 Temperature history of exact fin theory for M = 1 & dimensionless time dt = 1

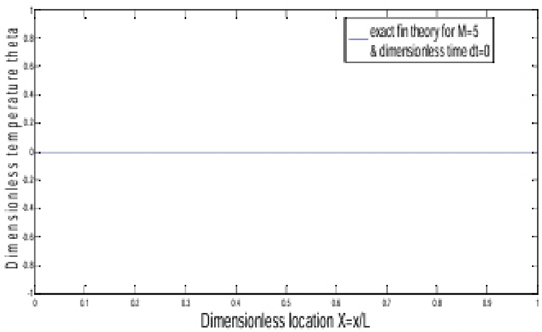


Fig.3.7 Temperature history of exact fin theory for M = 5 & dimensionless time dt = 0

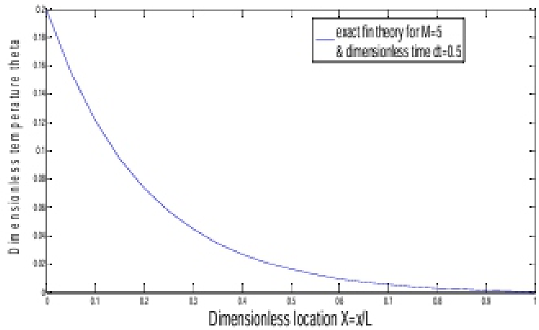


Fig.3.8 Temperature history of exact fin theory for M = 5 & dimensionless time dt = 0.5

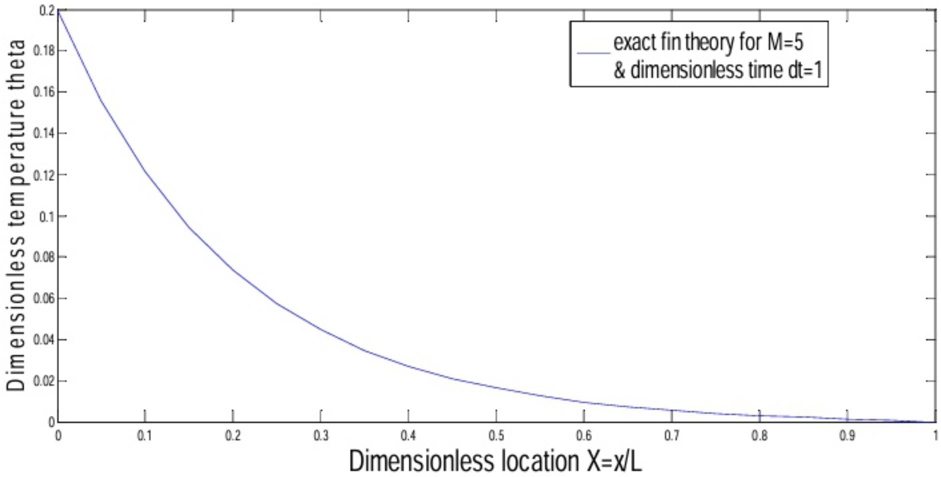


**Fig.3.9** Temperature history of exact fin theory for M = 5 & dimensionless time dt = 1

Fig. 3.7 to 3.9 shows the temperature distribution curve for exact fin theory, taking M = 5 & τ = 0, 0.5 & 1. Curve attains steady state for large value of M. Curve does not change much for large dimensionless time. For the exact fin theory, temperature was computed in the range as: [0 < x=L < 1 and 0 < αt/L2< 1] for fin parameter values M = 0.2, 1.0 and 5. This program was coded in Matlab.

## 4. Conclusion

The temperature distribution for long fin has been taken into account for exact fin theory. Following are the conclusions.

Complicated exact transient solutions can be simplified for temperature distribution analysis through Greens function method.

Convergence of the solution can be improved by replacing the series steady term with non-series finite steady term.

A unique solution is produced containing non dimensionless parameter for long fin case.

Larger value of M increases the transient response of fin.

The exact fin model can be a simple way to find temperature distribution associated with heat loss.

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# SCFCS: Supply Chain Factor Categorization Scheme

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## ABSTRACT

*The performance of the material-procurement decisions is heavily dependent on the combination of the different alternatives associated with every phase of the materials management process and the factors or factors that influence the selection among the different alternatives for each particular decision. These factors need to be extracted on a regular basis as decisions related to material management are ever present in a construction project. The identification of factors is a task that requires more attention, since factors related to different areas, such as schedule, suppliers, among others, need to be considered. These factors can be acquired from different sources such as historical databases, the internet, and suppliers, among others. The recognition and extraction process for the factors could be tedious and time consuming because the decision maker could be extracting the information from unstructured records that contain vast amounts of data. This paper describes a framework/structured approach developed for factor categorization.*

## 1. INTRODUCTION

Currently, there is no structured model to categorize the factors that need to be considered on the supply chain decision making process particularly for small scale industry[3]. The small scale industry needs a structured database design that can allow decision makers to review and categorize these factors[5]. This categorization could facilitate the storage and categorization of the factor information for future extraction and use. As part of this research, a structured approach was defined for factor categorization only. For a more complete system design and model specification, a similar approach desires to be developed for alternatives and performance measures. This development could be the basis for future research.

Based on the information gathered through interviews with the electrical contracting industry personnel and through extensive literature reviews, a system for classifying factors for material supply chain was developed. SCFCS, an acronym for Supply-Chain Factor Categorization Scheme, is a categorization structure for supply chain factors. The development of SCFCS begins with a hierarchical framework. This approach conforms to generally accepted methods of structured systems development. SCFCS will be the basis for future development of a relational database to share and organize factor information. In addition, the development of SCFCS could help industry in understanding how some of the particular database applications work. For example, SCFCS could give the firm an idea of how an Enterprise resource Planning (ERP) system was set up and the data that could be part of that system. In upcoming research efforts, this hierarchical framework could be developed into a relational database design[4].

For the development of SCFCS, the decision support systems (DSS) used in the materials management decision process are described as independent systems for each decision to be made. This means that each DSS extracts the information needed from a data source that contains the specific data required, in our case the SCFCS categories, to analyze that particular decision as described in Figure 1. The figure illustrates three of the decisions that are considered in the study.

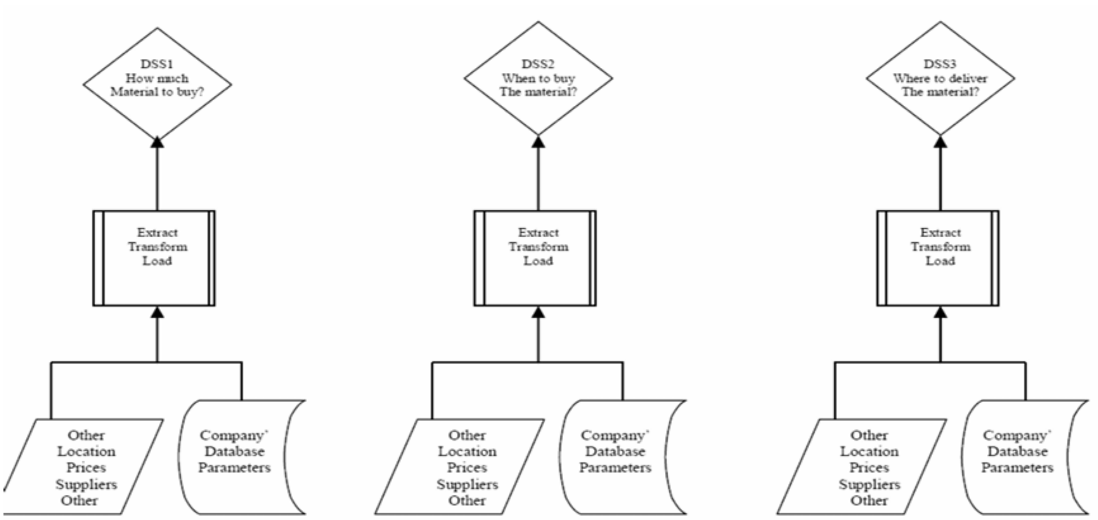
The activities required for database development [1] are project identification and selection, project instigation and planning, psychoanalysis, logical design, physical design, implementation and maintenance. In the project identification and selection activity, the range and general contents of the organizational database are set. In the project initiation and planning activity, the scope of the data involved in the development project is outlined. In the analysis activity, a detailed data model is produced and all the information needed for the information system is identified. In the logical design activity, the conceptual data is transformed into relations by using ER diagrams [6].

The physical design activity involves disk allocations and physical allocations of the databases. The accomplishment activity involves testing the database with programs used by the company. The maintenance activity involves tuning the database to keep it up to date with information generated and fixing problems.

The information requirements for the application to be developed are defined, the contents of the overall database of factors are described within SCFCS, the overall data needs for the material supply chain process are defined and detailed models that identify the data needed for the decision support system are identified.

There are several points that need to be addressed with respect to the development of SCFCS and the model:

1. Decision models are never perfect and are always being updated and enhanced. The hierarchical definition of SCFCS allows updating the factor categorization and structure of the system easily.



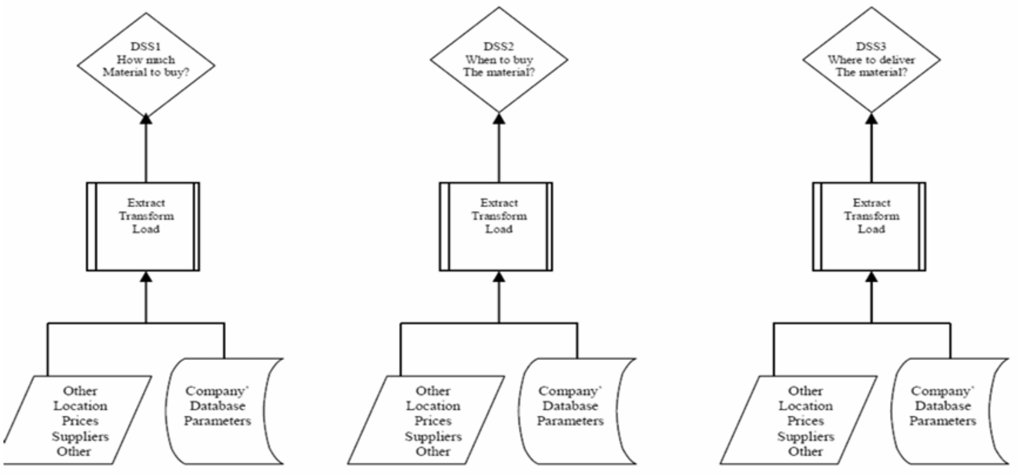



**Figure 1:** Description of Structure of the Decision Support Systems

3. Database design and data collection take a long time to complete.
4. The facts mentioned in points 1 to 3 imply that, in order to have the data available whenever a decision model is changed, the database must be built in anticipation of future decision-model developments. In other words, the database must be defined comprehensively with all possible decision models in mind. This is the approach taken in designing and investing in ERP systems and data warehouses.

**DEVELOPMENT OF SCFCS**

SCFCS permits classifying and organizing supply chain related factor information into various categories. This categorization can be used as the structure to create the database that will store the factor information. Factors needed by the decision maker at any instant can then be extracted from the respective category in the database under the SCFCS categorization.

The first step in the development of the system was to gather information from interviews with companies and literature review. Once the information was gathered, the decision nodes for material supply chain were identified, and the data needed as inputs (i.e. factors) and the data generated as outputs (optimal decision variables and performance measures) for all the decision nodes were also identified. Once the data were identified, categories under which the factors could be classified were defined for each decision. Examples of the categories include cost, schedule and storage. Categories could also contain sub-categories. For example, the cost category can be subdivided into direct and indirect cost. The factors are then classified into the respective category and subcategory, if applicable. Each category is comprised of factors that can directly influence that category. For example, some factors that are included in the storage category are capacity, cost, etc.

It could be argued that ERP databases that are currently available were designed to address decision support in all aspects of a business enterprise. However, the development of SCFCS presents the following research contributions:

1. It defines the database that would be extracted from ERP databases or other company data sources in order to support specific decisions.

2. It defines data that may have to be extracted from different corporate entities and different corporate databases (general contractor, sub contractor, suppliers, and owner).

3. It assists in the development of small-scale decision support that a subcontractor may utilize in the absence of an ERP system.

**Data Definition for SCFCS**

Figure 2 depicts the general structure of SCFCS. In a hierarchical diagram definition, this type of diagram could be referred to as a parent-child description. The entry point, or parent, is the decision to make. The categorization of the factors in SCFCS depends on this decision. Once the decision to be made is known, the next step is to identify the Category in which the factor fits. A Category is the main class used to classify a factor. Categories were selected based on the main information components that can be found in a typical construction project. Categories could contain Sub- categories that are used to further divide the Categories into components that could facilitate the categorization of the factors. For example, the Cost category can be further divided into two categories: Direct cost and indirect cost. The use of sub-categories allows classifying factors more specifically based on the cause that the factors could have on the overall decision system. For example, a contractor could easily identify that material not being available when needed creates an indirect cost associated to losses in productivity[8].

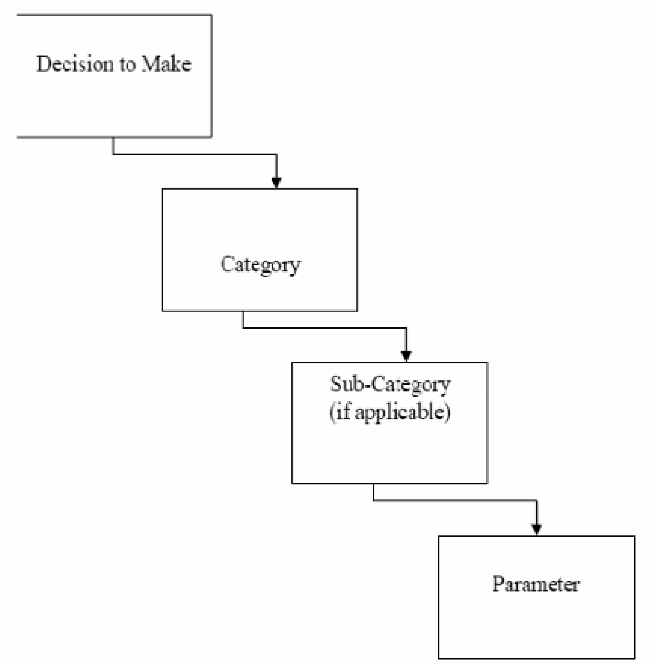



**Figure 2:** General Structure of the SCFCS System

The main categories identified are: Type of Material, Cost, Storage, Schedule, Supplier, Other and Plans and Specifications. Subcategories are used to further divide the Cost and Storage categories into direct or indirect cost and on-site or off-site storage. The factors are then classified into the appropriate category and subcategory. The factors needed for every decision to be analyzed are filtered from the SCFCS hierarchy.

SCFCS FOR THE 'HOW MUCH TO BUY' DECISION

The main categories that apply to this decision are cost, storage, schedule, supplier and other.

The storage category comprises two options: on-site storage or off-site storage. The options for on-site storage are to store in "sea cans" or trucks, store in work areas or store in the lay down areas. The factors associated with the on-site storage are storage capacity, storage costs, storage location, security, theft, loss and damage. The alternatives associated with off-site storage are warehouse, rented space and subcontractor's yard. The factors associated with the off-site storage are storage capacity, storage costs (rent and transportation), storage location, security, theft, loss and damage. Another category associated with this decision is the schedule.

Factors under this category include progress of work, productivity, uncertainty in schedule, work to be done, when to use the material, planned vs. actual (i.e. extra work, changes), quantity to install, order to install or order to store. The other categories associated with this decision are supplier and other. The total cost of materials includes direct costs and indirect costs. These are two subcategories under the Cost category. Direct costs are comprised by materials selling cost distribution, distributor's cost, transportation costs, and disposal. Indirect costs may include costs due to misplacement, damage, loss, cost of placing processing and paying of material, cost of receiving, storage, issuing, among others.

**SCFCS FOR THE 'WHAT MATERIAL TO BUY' DECISION**

The type of material to use in a construction project is specified in the specifications and in the drawings. Consequently, it is expected that plans and specifications comprise one category for factors for this decision. For this decision, the main considerations are the brand of the material to buy and from which supplier to buy it. The main categories for this decision are Cost, Plans and specifications, Schedule and Supplier.

The total cost is comprised by direct and indirect cost. Direct costs include the purchasing cost, discounts, and ordering. Indirect costs include cost associate with backorders. The supplier category is important because the brand of the material to be used in a particular project could be specified in the contract documents. Some materials are only carried by specified suppliers; therefore this material needs to be acquired from those suppliers. If the material brand is not specified, the contractor can select the sourcing source either through bidding, negotiated contract or a blanket order.

## SCFCS FOR THE 'WHERE TO DELIVER' DECISION

The main categories that apply to this decision are: cost, schedule, storage and supplier. The contractor needs to consider the direct storage cost of each alternative before making a decision on where to send the material for storage. Moreover, the contractor needs to consider other indirect costs associated with each storage alternative such as damage while the material is stored, loss or theft. Any of these factors can greatly affect the availability of material when needed, even more if the material being stored is a critical material. Absence of a critical material when needed affects the construction schedule greatly. The production and availability of a critical material requires long lead times, therefore it is very important to consider the storage location for such material.

The space available at each storage alternative is critical when making this decision. If there is available space and the material will be used in the near future, the contractor should consider storing the material at the jobsite. However, as seen from the SCFCS diagram, this decision is based on space availability, storage restrictions, storage fees, possibility of damages and loss.

## SCFCS FOR THE 'WHERE TO STORE ON SITE' DECISION

Often the available space for storage in the lay down areas is limited. The numbers of trades working at the same time influence the space available for storage in the lay down areas as well as the available space for storage in the building. In addition, the progress of the work and the number of trades working in the same area influence the number of times that material stored on the floor of the building needs to be moved around to free space for the other trades. These are some of the factors that affect the decision on where to store the material on the construction site. The main categories for this decision are cost, schedule, storage and other. Under the other category, the possibility of material being damaged is encountered. The contractor needs to consider the possibility of material being damage when selecting a storage location. Quality is a very important aspect to achieve in a construction project. If material is damaged while stored and the contractor decides to store the damaged material not only re- work would have to be done, but, in addition, the contractor might not get future jobs due do this behavior. Therefore, the contractor should avoid damages and the cost associated with reordering material

## SCFCS FOR THE 'WHEN TO DELIVER' DECISION

The main categories for this decision are cost, storage, supplier, schedule and other. The performance of the supplier plays a critical role in this decision. If the supplier is a reliable source, the contractor could request deliveries the day before the material will be used. Otherwise, the contractor will have to order the material in advance and store it at the jobsite.

## SCFCS FOR THE 'WHEN TO BUY' DECISION

The main categories for this decision are type of material, cost, storage, schedule, supplier and other. As discussed earlier, the lead time for the material depends on the type of material to be bought.

The contractor should consider to buy material early if some discounts could be achieved by ordering such material early or if increases in material cost are expected in the near future. An example of material that could increase in cost is cable. Copper prices fluctuate and this affects the price of cable. However, the contractor should consider the storage cost of having this material early against the savings that could be achieved.

## CONCLUSION

The research presented in this document aimed at designing an integrated system of decision- support tools for material procurement for the small scale industry particularly an electrical industry. An integrated approach for material procurement provides better decisions on what to order, how much to order and where to deliver.

Future research will be needed to develop a more complete framework integrating other decisions needed in areas such as supplier selection and preliminary material scheduling during the pre-fabrication phase. A fully integrated approach will better improve communication and minimize gaps in information flow among all the parties and departments involved.

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