TANDOOR THERMOELECTRIC POWER GENERATOR

FOR DEVELOPING NATIONS

Prepared and Submitted

by

Abhi Jay Krishnan

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i. Abstract

Humble looking and a low cost wood fired flat bread ovens like Tandoor ovens are a good source of waste heat energy. Tandoor is used for cooking in developing countries like Azerbaijan, India, Turkey, Iran, Armenia, Pakistan, Uzbekistan, Afghanistan, the Balkans, the Middle East, Central Asia as well as Burma and Bangladesh etc. An affordable source of electricity from heat - even if it is not of very high power - can make a major difference in the quality of the life of the people of these countries.

This project aims to harvest waste heat energy from a commonly used Tandoor oven by converting it into electricity using a low cost thermoelectric converting device. The well known Seebeck-effect based thermopiles are used for harnessing the waste heat from the oven and storing it a rechargeable battery. Ceramic based custom built heat spreaders and ceramic wool insulation etc ensure adequate temperature temperature difference at required area without using an external power source.

ii. Acknowledgment

I thank Global Indian International School for giving an opportunity to participate in Nanyang Technological University IEEE Science Symposium.

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1.0 Introduction

Most developing nations across the globe are in need of every bit of energy savings to support their growth. Reducing the energy usage by curtailing development efforts may slow the growth process of these countries. At the same time issues like global warming [1] demands lower and lower levels of carbon emissions and that requires new sources of energy that will not add significantly higher emissions levels.

While there is considerable investments made in solar power, its ability to reach a common man in developing countries is still in a developing stage[2]. In most of the growing countries such an energy source is not within the reach of a common man without a significant financial support from the government.

In this situation an energy conservation solution that can seamlessly fit into the life of a common man in developing countries can have a major impact in the way they live. One way to achieve is to convert waste heat from a commonly available source to electrical energy.

1.1 A Tandoor [3] solution: A commonly available high energy mass heat source in developing nations:

Humble looking and a low cost wood fired flat bread ovens like Tandoor ovens are a good source of waste heat energy. According to an encyclopedic information , Tandoor is used for cooking in developing countries like Azerbaijan, India, Turkey, Iran, Armenia, Pakistan, Uzbekistan, Afghanistan, the Balkans, the Middle East, Central Asia as well as Burma and Bangladesh[4].

Fig1.1 A tandoor oven in Uzbekistan

1.2 Other potential sources of heat energy (A self brain storming session):

Kitchen LPG stove, Automobile and Other engines, Body heat, Heating devices like Iron box, Water heaters, Bread Toaster, Solar heat energy, Geo thermal energy, Exothermic reactions, Nuclear energy, Electronic devices such as Computers, Television, Mobile phones etc, Light bulbs and other light producing devices, Friction breaks in cars and other automobiles, Furnaces, Hot water springs etc.

1.3 Why is a Tandoor oven a fitting choice for waste heat recovery?

1.2.1 It is my belief that to conserve energy in large scale it is necessary to target the most basic energy sources people use in their daily life. Adding up all small energy

savings in a global scale is likely to make a larger impact than the savings from randomly selected large scale projects.

1.2.2 There are countries in the world were the people have no access to electricity[5] even today. The governments and international initiatives like UNDP [6] are in relentless effort to satisfy the basic needs of the people and improve their quality of life. An affordable source of electricity from heat - even if it is not of very high power - can make a major difference in the quality of their lives.

1.2.3 Tandoor oven remains hot for long periods during the day and night. The oven temperature can reach upto 480°C [4] .

1.2.4 Tandoor is widely used in developing nations in highway diners [7]. A Tandoor powered electric source can provide basic lighting and communication facilities to simple restaurants operating along side of major roads or highways where conventional power is not available. A basic lighting facility will allow such establishment operate at more completable locations even at night. For example a restaurant could be set up at a location where there is good traffic but dose not have conventional power source.

1.2.5 A solar power source could used but that would been considerable additional investments at comparable energy efficiency levels [8]. Tandoor thermoelectric generators are not effected by whether changes and will be functional as long as cooking is going on irrespective of the time of the day. The embers remains hot for long hours even after cooking is finished.

1.3 Harvesting waste heat from a Tandoor oven:

Waste heat harvesting[9] or converting heat into usable electrical energy is not an entirely new concept There are numerous commercially available products [10] that can convert heat into electricity at various converting efficiencies. However, based on my limited research knowledge these products may not provide an energy solution to a common man in a developing country. The heat for a tandoor is traditionally generated by a charcoal fire or wood fire, burning within the tandoor itself. According to Wikipedia , the oldest examples of a tandoor were found in the settlements of the ancient Indus Valley Civilization now in Pakistan[4].

2.0 Materials & Method:

Fig 2.1 A Tandoor oven

2.1 Thermoelectric effect (Seebeck/Peltier) effect:

Seebeck effect [11], production of an electromotive force (emf) and consequently an electric current in a loop of material consisting of at least two dissimilar conductors when two junctions are maintained at different temperatures. The conductors are commonly metals, though they need not even be solids. The German physicist Thomas Johann Seebeck discovered (1821) the effect. The Seebeck effect is used to measure temperature with great sensitivity and accuracy and to generate electric power for special applications [12]. The thermoelectric voltage developed per unit temperature difference in a conductor is called a Seebeck coefficient. Only the net Seebeck voltage difference

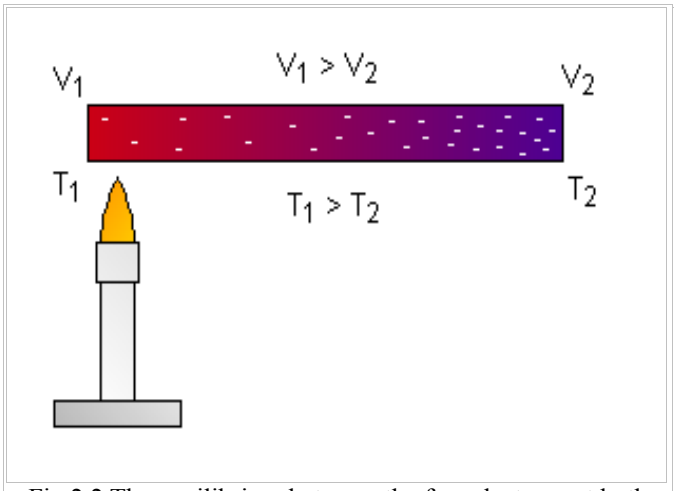


Fig 2.2 The equilibrium between the free electrons at both ends of the wire is broken when one side is heated,creating a current [13]

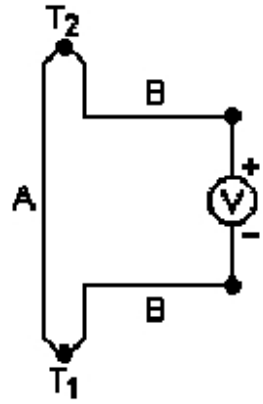


Fig 2.3 Diagrammatic representation of a circuit showing Seebeck effect [13]

between different metal can be measured.

S → Seebeck coefficient

dV → change in voltage

dT → change in temperature

S = dV/dT

If T_1 &T_2 are the temperature difference across the two ends and if we integrate the above formula we get: $$V = \int_{T_1}^{T_2} (S_{\mathrm{B}}(T) - S_{\mathrm{A}}(T))\, dT.$$

2.2 Thermoelectric generator using Seebeck effect:

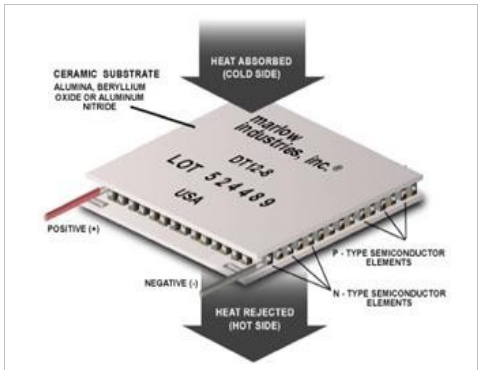


Fig 2.4 A Peltier cell

After exploring different ways of conversion of energy from one form to another, a thermoelectric generating device using Seebeck effect seems to be the most suitable option to harvest waste heat from a Tandoor oven. While it is obvious that this technology is being used in several applications as in thermocouple etc, I focused my thoughts to find way of using this effect to generate power from a tandoor oven.

2.3 Thermocouples and thermopiles:

A thermocouple is a sensor for measuring temperature. It consists of two dissimilar metals, joined together at one end, which produce a small unique voltage at a given temperature. This voltage is measured and interpreted by a thermocouple thermometer. Thermocouples are available in different combinations of metals or calibrations. The four most common calibrations are J, K, T and E. Each calibration has a different temperature range and environment, although the maximum temperature varies with the diameter of the wire used in the thermocouple [14].

A thermopile [15] is made of thermocouple junction pairs connected electrically in series. The absorption of thermal radiation by one of the thermocouple junctions, called the active junction, increases its temperature. The differential temperature between the active junction and a reference junction kept at a fixed temperature produces an electromotive force directly proportional to the differential temperature created.

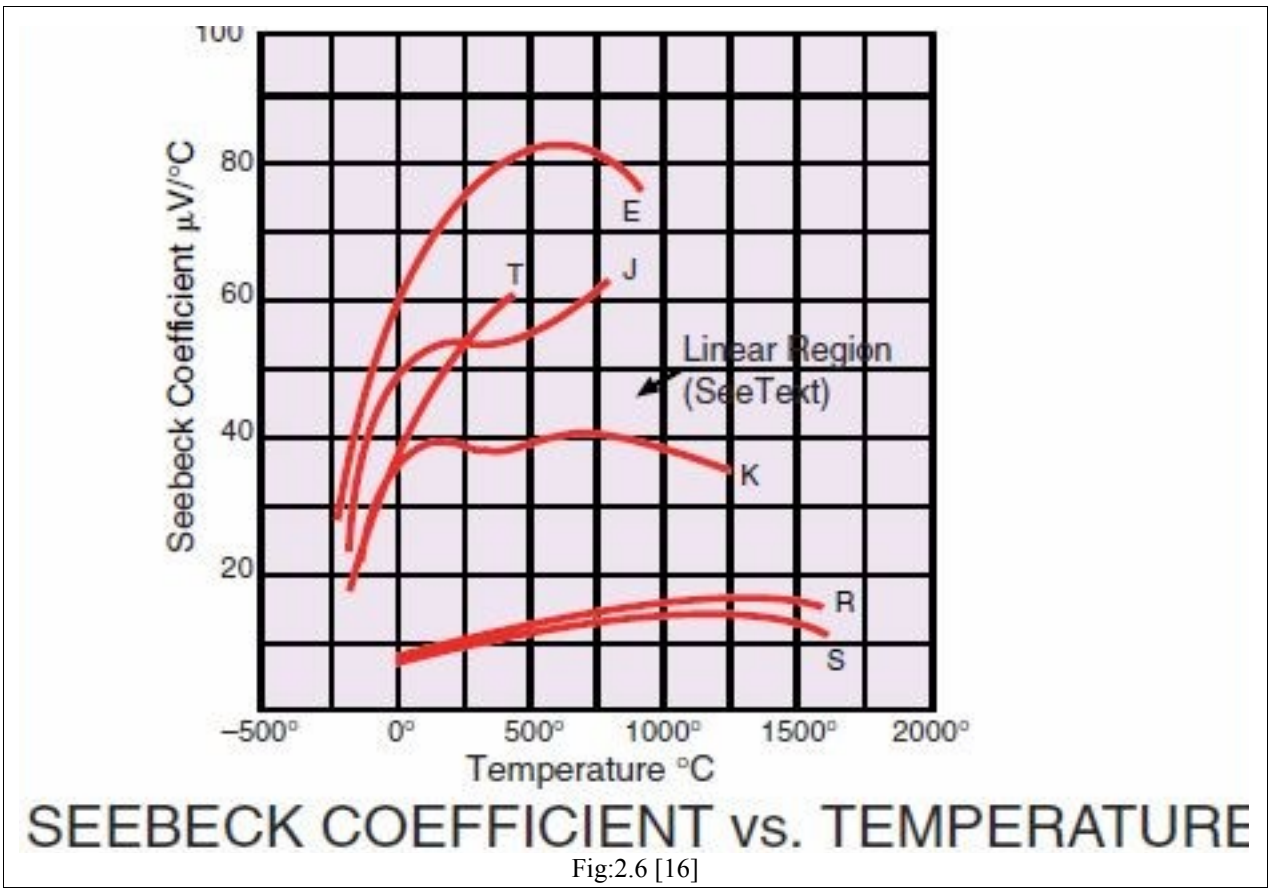


Fig:2.6 [16]

2.4 K Type thermocouple:

Type K is the 'general purpose' thermocouple. It is low cost and, owing to its popularity, it is available in a wide variety of probes. These thermocouples are available in the -200 °C to +1200 °C range. Sensitivity is approx 41 µV/°C [17]. Type K was specified at a time when metallurgy was less advanced than it is today, and consequently characteristics vary considerably between samples. One of the constituent metals, nickel, is magnetic; a characteristic of thermocouples made with magnetic material is that they undergo a step change in output when the magnetic material reaches its Curie point (around 354 °C for type K thermocouples). Curie point, is the temperature at which a ferromagnetic or a ferromagnetic material becomes paramagnetic on heating. Hence after the curie point the electrical conductivity of k type thermocouples increases. As the Tandoor oven operates at temperatures exceeding 350°C, the current flow though the thermopile will incur lesser resistance.

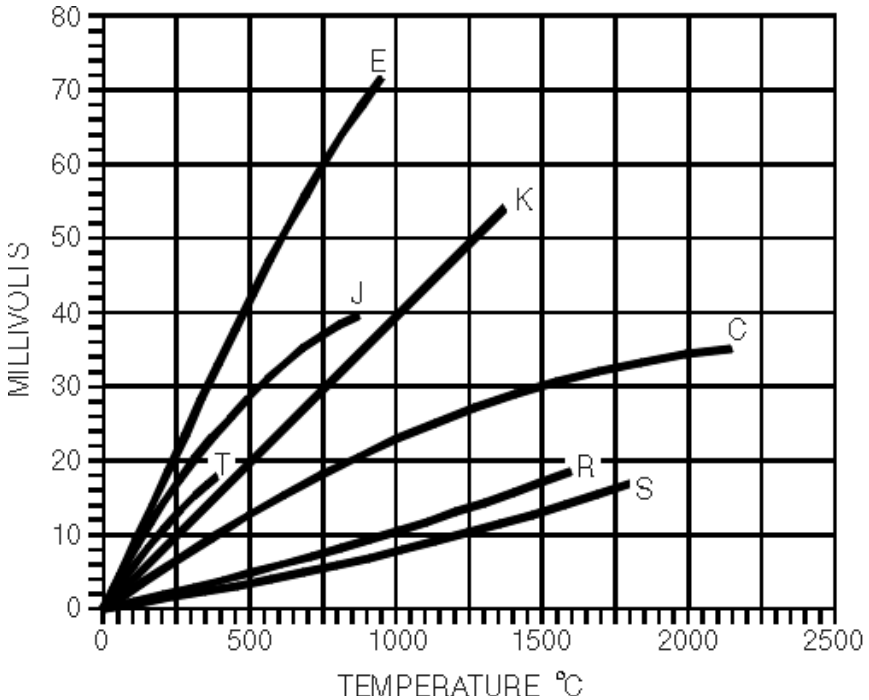


Fig 2.6 Thermocouple temperature-vs-voltage [17]

2.5 Constructing a Thermopile using Alumel & Chromel wire :

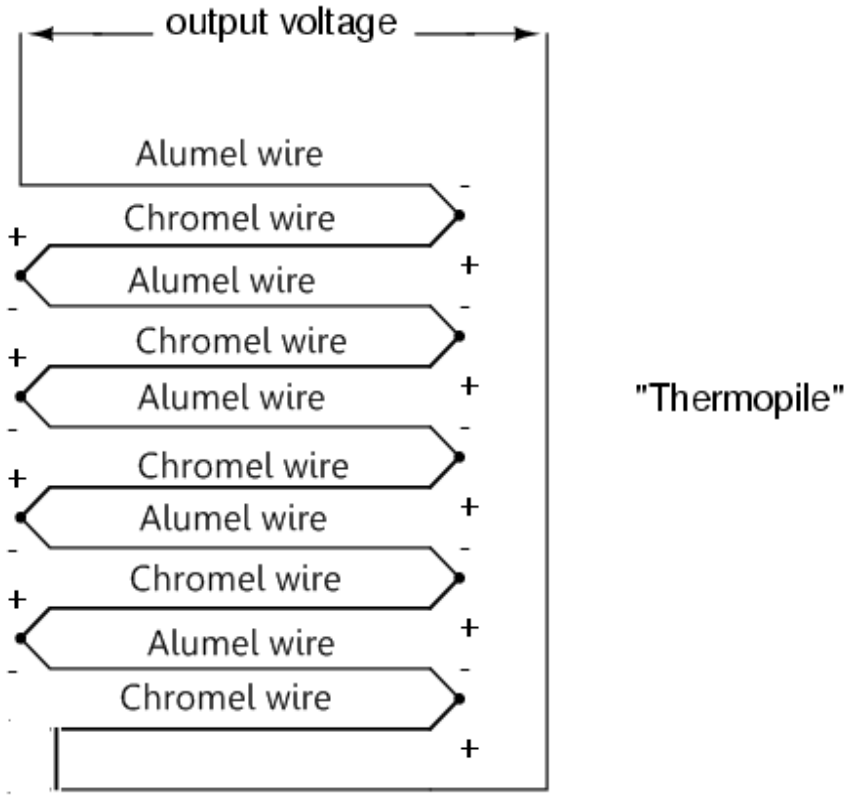


Figure 2.7 : Constructing a Thermopile using Chromel & Alumel wires

First step is to make a thermopile using a suitable thermocouple. A' K type chromel – Alumel wires as it gives a steady voltage upto 750°C (Ref fig:2.7). J & E types give better voltage levels but the predictability of output voltage is much lower [Ref: Fig2.6 & 2.7].

2.6 High temperature insulation

We also need a high temperature to insulate the inner earthen pot, so that the heat loss from the oven is minimised and it does not reach the ceramic heat sink (Ceramic heat sink will be explained in the next session). For this one of the following materials can be used.

2.6.1 Mineral wool [18]:

Mineral wool , mineral fibres or man-made mineral fibres are fibres made from natural or synthetic minerals or metal oxides. The latter term is generally used to refer solely to synthetic materials including fibre glass, ceramic fibres and rock or stone wool. Industrial applications of mineral wool include thermal insulation (as both structural insulation and as pipe insulation), filtration, soundproofing, and germination of seedlings. Mineral wool is made from molten glass, stone or slag that is spun into a fiber-like structure. Inorganic rock or slag are the main components (typically 98%) of stone wool. The remaining 2% organic content is generally a thermosetting resin binder (an adhesive) and a little oil .

2.6.2 Calcium silicate wool [19]:

Non-asbestos Calcium Silicate insulation board and pipe insulation feature with light weight, low thermal conductivity, high temperature and chemical resistance. Calcium Silicate is rigid, high density material used for high temperature applications ranging 250 ^{o}F (121 ^{o}C) - 1000 ^{o}F (540 ^{o}C).It has very good compressive strength and noncombustible .

2.6.3 Glass wool [20]:

Glass wool is an insulating material made from fiberglass, arranged into a texture similar to wool. Glass wool is produced in rolls or in slabs, with different thermal and mechanical properties. Glasswool is made from recycled glass bottles, so it is ultra-eco-friendly. It is easy to handle and install, plus it is the most cost-effective insulation available. But it said to be a category 3 carcinogen by A 2002 summary by International Agency for Research on Cancer. So extra precautions has to be taken while handling

this materiel.

2.7 Thermally conductive & Electrically insulating heat sink/Spreader:

2.7.1 Aluminum nitride powder [21]**:** It has a relative high thermal conductivity for an electrical insulating ceramic (70–210 W/m−K for polycrystalline material, and as high as 285 $W \cdot m^{-1} \cdot K^{-1}$ for single crystals).

2.7.2 Boron Nitride Powder [21]**:** Boron nitride is another Thermally conductive and electrically insulating ceramic material. It is shows very high thermal connectivity more than 300 $W.m^{-1}k^{-1}$ for a single crystal.

2.8 High temperature adhesives [22]:

Commercially available Alumina based high temperature adhesive. Good conductor of heat, electrical insulator and sets fast. Other high temperature ceramic adhesive can also be used.

2.9 DC-to-DC converter

A DC-to-DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. The thermopile output need to be converted into a suitable voltage level to charge a suitable rechargeable battery.

2.10 Method

2.10.1: Constructing a Thermopile using K type thermocouple wire

Thermopile can be constructed by connecting each component of the thermocouple wire in series alternatively, forming a circular loop as shown in the figure 2.8. When we form a loop of a series of Chromel and Alumel wires we end up with a positive terminal (Chromel) and a negative terminal (Alumel). For this to happen we should have equal number of Chromel and Alumel wires. We will need *two such loops consisting of five hundred junctions each to generate about 17W of power* [Ref: Table 1]. Normal tandoors have up to 1.5 meter circumference [25], so it can easily fit thermopile loops of five hundred junctions. These two loops will be connected in series and the positive and negative ends will be connected to socket. The hot junction will be introduced to to the burning ember and cold junction will be inserted into a small hole drilled into the thick Aluminum casing containing a patch of high temperature adhesive.

2.10.2 Overall construction

The hot junction of the thermopile will passed through the walls of the earthen pot. Then the rest of the wire will pass through a very thick layer of Aluminum nitride (or boron

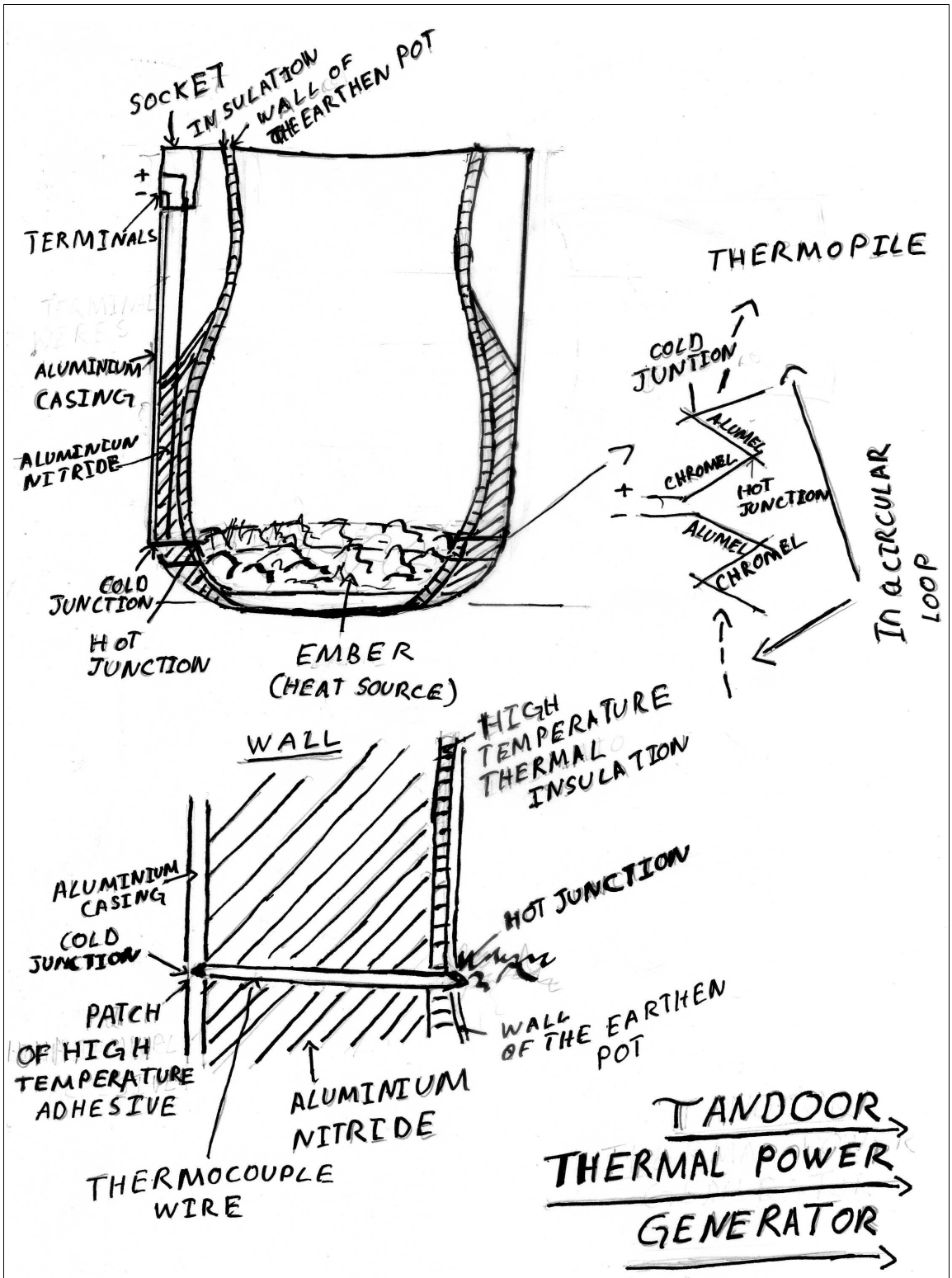


Fig 2.8 : An Artistic representation of Tandoor Thermal Electric Power Generator

nitride), this layer is nearly 2.7" thick. The cold junction attached to the Aluminum frame with a high temperature adhesive coating over the junction. The outside of the earthen pot will be covered with a high temperature insulator. The loops of thermopile forms are situated around the earthen pot only the hot junction will be introduced into the pot. The overall construction is depicted in the figure 2.8

2.10.3 Working Principle :

A Tandoor powered thermoelectric generator works on Seebeck principle. A current is induced in the loop when a closed loop was formed of two metals joined in two places with a temperature difference between the junctions.

2.10.4 Explanation on working of a Tandoor Thermoelectric Power Generator:

When we burn coal/wood inside the earthen pot the hot junction gets heated to a temperature of up to 480^0c.The heat energy will pass through the wire and as soon as it enters the Aluminum nitride layer the heat energy will be absorbed and spread at high rate due to its excellent thermal conductivity [26]. This heat transfer will allow the cold junction to maintain a lower temperature. As the cold junction is attached to an Aluminum casing using a thermally conductive ceramic adhesive. The rest of the heat will be passed onto the Aluminum casing which acts as a heat sink. Aluminum nitride layer also expected to be cooled by the Aluminum heat sink.

Since the hot junction is approximately at 480^0c and the cold junction is closer to the room temperature, a potential difference will be created across the circuit, creating a current through the wire. By using a thick AWG 8 K type wire the overall The high temperature insulator will around 12 Ω at room temperature. Beyond curie point the resistance will further reduce.

To prevent the further heating of Aluminum nitride layer and the thermocouple wires an thermal insulation layer using mineral wool/calcium silicate/glass wool is provided between the earthen pot and Aluminum nitride layer. Since there is a insulating layer outside pot the efficiency of the cooking will also increase, saving fuel (no heat will be lost to the out side of the pot through the walls).

A DC-DC converter can be used to to convert the output voltage to a suitable level (eg:12Vdc) so that it can be used for trickle charging a rechargeable battery on a continuous basis.

3.0 Results: Table 1 - Calculations showing expected power out from a Tandoor thermoelectric power generator [27]

AWG Gauge	Resistance (Ω)	No. of Junctions	Length / Junction (ft)	Total Resistance (Ω)	Voltage/jn/°C (V)	Temp Diff (°C)	Overall Voltage (V)	Current (A)	Power (W)
8	**0.04**	**1000**	**0.33**	**12.05**	**4.10E-005**	**350**	**14.35**	**1.19**	**17.1**
12	0.09	1000	0.33	30.23	4.10E-005	350	14.35	0.48	6.81
14	0.15	1000	0.33	48.38	4.10E-005	350	14.35	0.3	4.26
16	0.23	1000	0.33	76.92	4.10E-005	350	14.35	0.19	2.68
18	0.37	1000	0.33	122.3	4.10E-005	350	14.35	0.12	1.68
20	0.59	1000	0.33	194.5	4.10E-005	350	14.35	0.07	1.06

AWG Gauge : American Wire Gauge of ISA K-Type Chromel-p/Alumel wire

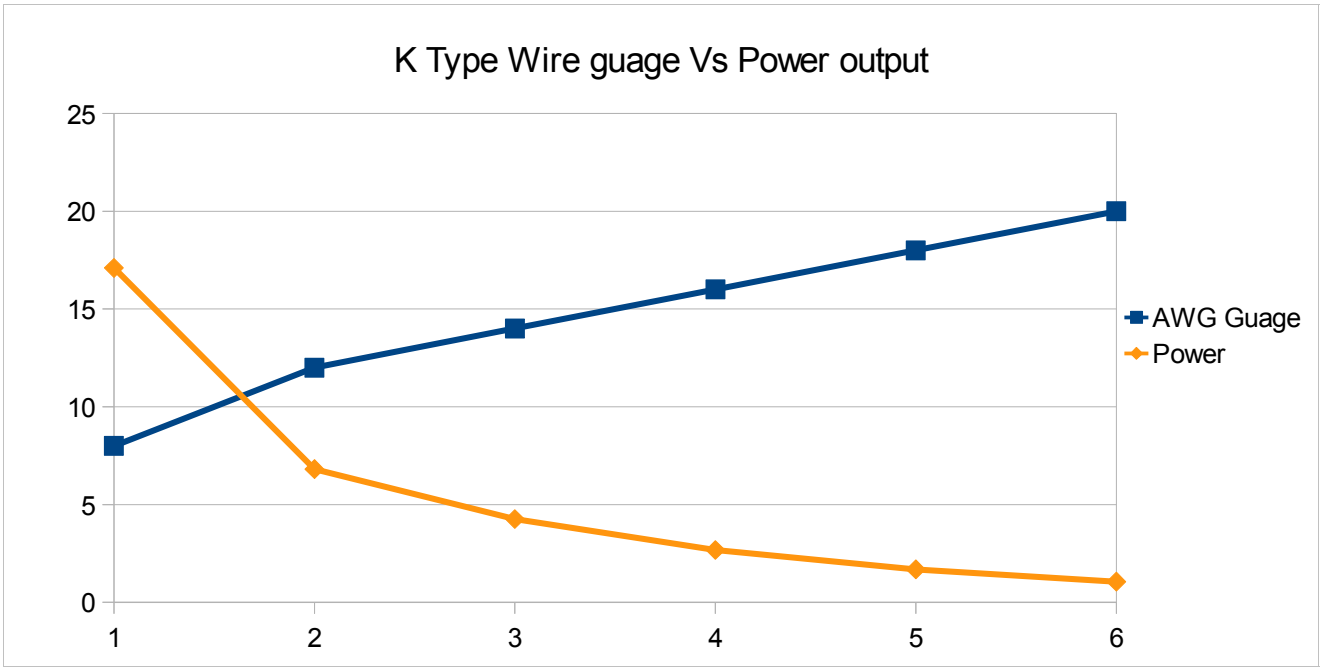
Resistance(Ω) : Resistance in Ohms per Double Foot at 68°F.

EXAMPLE: What is external resistance to my instrument if I use a 20 gauge Chromel/Alumel thermocouple 3 feet long and 14 gauge Chromel/Alumel lead wire 20 feet in length?

ANSWER: 3 x .5894 = 1.7682 ohms

20 x .1466 = 2.932 ohms

Total 4.7002 ohms



4.0 Conclusion:

In developing countries the Tandoor restaurants are often found in remote locations along the major roads that crisscross the country. They are often humble in nature but provides cost effective and nutritious food for travelers. Often they have an open air environment that do not require much illumination etc. If each of the restaurants has a simple thermal tandoor power generating unit it allows them to set up a restaurant even in road side locations where no traditional power source is available. For example 'Dabas' are one of most popular highway diners in developing countries.

4.1 Dhaba

In India and Pakistan highways are dotted with local restaurants popularly known as dhabas [28]. They generally serve local cuisine, and also serve as truck stops. In India they are most commonly found next to petrol stations, and most are open 24 hours a day. Since most Indian truck drivers are of Punjabi descent, and Punjabi food and music is quite popular throughout India, the word dhaba has come to represent any restaurant that serves Punjabi food, especially the heavily spiced and fried Punjabi fare preferred by many truck drivers. The word has come to represent sub-continental cuisine so much that many Indian restaurants in Europe and America have adopted it as a part of the name. Dhabas were characterized by mud structures and cots to sit upon (called 'chaarpai' in Hindi) while eating. A wooden plank would be placed across the width of the cot on which to place the dishes. With time, the cots were replaced by tables. The food is typically inexpensive and has a 'homemade' feel to it.

Fig 1.2 A typical highway diner in India

4.2 Advantages of the tandoor thermal power generator

The tandoor thermal power generator – unlike solar power generators – remains hot for most part of the day. Solar panels need large open area to harness electricity, even a 15W solar panel needs at least 204*280*18 (mm) space and weighs more than a kilogram. Most of them are expensive [29] to be installed at highway diners in developing countries. Unlike the solar panels the tandoor thermal power generator can do cooking and produce electric current at the same time. It also can be used for trickle charging a battery (Trickle charging, or float charging)

means charging a battery at a similar rate as its self-discharging rate, thus maintaining a full capacity battery. Most rechargeable batteries, particularly nickel-cadmium batteries or nickel metal hydride batteries, have a moderate rate of self-discharge, meaning they gradually lose their charge even if they are not used in a device.)

4.3 Limitations of Tandoor thermal power generator:

The main limitation of this devise is that it produces low levels of power compared to the conventional power sources. Another limitation of this instrument is that it wont produce a steady current a DC-DC converter has to be used to steady the current. These limitations can be minimized by adopting the following methods

- Using more number of junctions to increase the power output from a thermopile.
- Using a thermocouple showing least deviation in the potential difference vs temperature graph.
- Using the most effective materiel for creating the temperature difference between the two junctions. Also reducing the length of the thermocouple wire .
- Using a twisted wire cable for thermocouple wires so that the resistance will be reduced ,since resistance is the main culprit for low power output.

4.4 Recommendations:

This concept can be adapted to generate power from various other heat sources. In such cases a thermocouple based thermopile could be replaced with a higher efficiency semiconductor technology based thermoelectric power generating device. Most of the such devices can operate upto 200°C. Thermocouple The following sources can be in cooperated:-

4.5.1 Industrial Furnaces:

An industrial furnace or direct fired heater, is an equipment used to provide heat for a process or can serve as reactor which provides heats of reaction. Furnace designs vary as to its function, heating duty, type of fuel and method of introducing combustion air. A large potential difference can be created inside a furnace due to a large heat source and the power produced from it will be a large amount. But the materials used , should be able to withstand the drastic temperature.

4.5.2 On the base of room temperature deference:

In Arctic and Antarctic regions the deference between the temperature inside the house/tents and outside the house/tents can be used to generate power .The hot junction

of the thermocouple can be placed near the fire place or heaters the cold junction can be extended to the outside of the house where the temperature is below o^0c.

4.5.3 Hot water springs: Naturally available hot water springs can be used for generating power. Such a power can be used for proving simple source of power at tourist attraction spots.

4.5.4 Exothermic reactions: Waste heat from exothermic reactions can be used to generate electricity.

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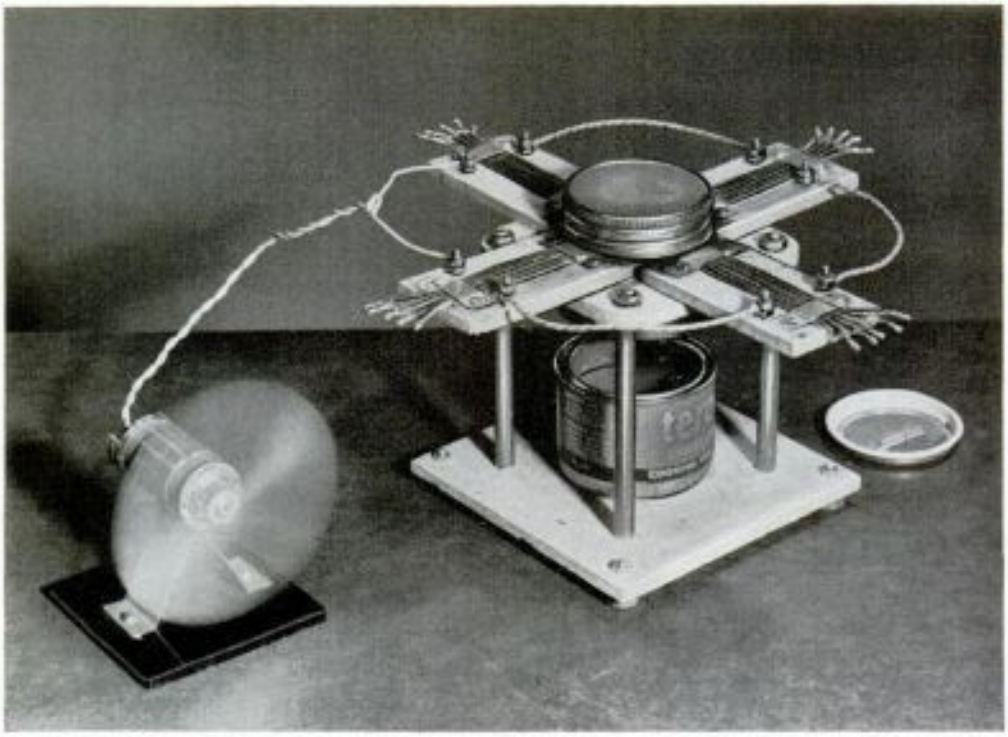
Appendix 1



NO, IT'S NOT PLUGGED IN! A thermoelectric battery converts canned heat into power to run this tiny fan

Fun with a Homemade THERMOPILE

By Harold P. Strand

WE'RE ALL FAMILIAR with everyday demonstrations of electricity converted into heat—the common hotplate and scorched insulation are examples. But fewer of us have actually watched the *reverse* process of heat being converted into a practical source of electric power.

Here are plans for a simple thermoelectric battery—or thermopile—that generates enough electricity to set a fan whirring. It's fun to build, and makes an ideal Science Fair project.

A German professor named T. J. Seebeck is credited with the discovery, in 1821, that when the junction of two dissimilar metallic conductors is heated, an electric current is produced. Over the years since, this phenomenon has been explored by many experimenters, with the result that a number of thermoelectric batteries have been developed for generating small amounts of electricity. Thermocouples, used today in industry for measuring temperatures, were also a result of Seebeck's discovery. However, as a source of practical power, the "Seebeck Effect" has remained relatively inefficient.

Recently, modern laboratories have taken renewed interest in this system of obtaining electricity without moving parts. Improvements have been made through the use of semi-conductors and new techniques which may eventually result in an efficiency comparable to that achieved by currently-used methods of generating electricity. There is now every indication that further research may lead to exciting developments in this field.

Unfortunately, semi-conductors of a type suitable for thermoelectric experimenting by amateurs are not readily available in a form easily handled without laboratory experience and equipment. However, we can conduct some very interesting experiments with thermocouple

Appendix 2

Last Updated: Tuesday, 28 June, 2005, 13:02 GMT 14:02 UK

Reliance to set up highway diners

By Zubair Ahmed
BBC News, Mumbai

Indian industrial giant Reliance has announced plans to set up a chain of highway diners for lorry drivers and well-heeled travellers alike.


Dhabas are found on highways across India

Until last week, Reliance Industries was the flagship of the now divided giant Reliance Group.

It will start the diners, known locally as dhabas, on roads across India.

The dhabas, generally run by village entrepreneurs, famously cater home-made food to long distance truck and bus drivers and passengers.

Home-style cooking

Dhabas are ubiquitous Indian diners found on every highway across the country and frequented by truck drivers and travellers.

They are famous for hearty, home-style cooking and are open round-the-clock.

Reliance Industries says it will set up 145 food and lodging outlets across the country.


Huge potential seen in highway hospitality

The company says it will have two types of dhabas - the one catering to the truckers will be called A1 Plazas.

The other, aimed at upmarket travellers, will be known as Refresh.

According to a Reliance Industries spokesman, these outlets will be set up on the premises of Reliance fuel outlets on India's national highways.

Huge potential

Reliance Industries will be the first organised private player to enter the roadside eateries and accommodation business.

Highway hospitality in India is currently an unorganised business.

Though some government-run oil companies have air-conditioned food plazas on the highways, they are not spread across the country.

Experts say the entry of Reliance may open the doors for other big players to join a business whose potential has not been tapped.

Also, new six-lane expressways and highways being built in many parts of the country further enhance the opportunities for highway hospitality.

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