REVIEW OF INVESTIGATIONS IN ECO-FRIENDLY THERMOACOUSTIC REFRIGERATION SYSTEM

by

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To reduce greenhouse gas emissions, internationally research and development is intended to improve the performance of conventional refrigeration system also growth of new-fangled refrigeration technology of potentially much lesser ecological impact. This paper gives brief review of research and development in thermoacoustic refrigeration also the existing situation of thermoacoustic refrigeration system. Thermoacoustic refrigerator is a novel sort of energy conversion equipment which converts acoustic power into heat energy by thermoacoustic effect. Thermoacoustic refrigeration is an emergent refrigeration technology in which there are no moving elements or any environmentally injurious refrigerants during its working. The concept of thermoacoustic refrigeration system is explained, the growth of thermoacoustic refrigeration, various investigations into thermoacoustic refrigeration system, various optimization techniques to improve coefficient of performance, different stacks and resonator tube designs to improve heat transfer rate, various gases, and other parameters like sound generation have been reviewed.

Key words: *thermoacoustic refrigeration, operating conditions, working fluid, optimization techniques, performance*

Introduction

Since the introduction of modern refrigeration technology at the beginning of 19th century there has been significant increase in their use. Now it is more or less not possible to visualize living with no refrigeration and air conditioning systems. At present, mostly cooling achieve by means of vapor compression equipment's using specific refrigerant which able to modified to any requisite temperature. To attain these properties, chlorine, carbon, fluorine, and blends of hydrogen are utilized in different proportions. Depending on these proportions, with regards to refrigeration, refrigerant not only show a particular set of properties but also responsible for global warming and ozone depletion. From the time when discovery of undesirable effects of these refrigerants, the area of refrigeration and air conditioning is shifting away from conventional refrigerants and continuously investigating for a substitute. Thermoacoustic refrigeration is a substitute refrigeration technology that can provide cooling without using any environmentally damaging substance.

Thermoacoustic refrigeration is becoming popular refrigeration technology. Loudspeakers or electro-dynamic shakers convert electrical power into acoustic power. Besides, heat can be produced from sound waves. Figure 1 shows a schematic drawing of sound wave thermoacoustic refrigerator (TAR). This technology utilizes sound effect to pump heat across a

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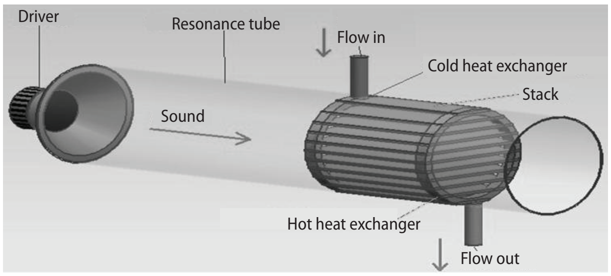

Figure 1. Sound wave TAR

temperature gradient. This is relatively easy to implement as well as inexpensive. Since there are no moving parts, the system can be much more extensive and may have robust operational lifetime. The concept of thermoacoustic naturally comes to mind when thinking about sound and temperature. Both phenomena involve the oscillation of particles. Sound is a pressure wave that transfers kinetic energy from one air parcel into the next using compression and expansion of the medium.

A thermoacoustic device uses a fluid medium (gas) to accomplish work within the stack (stack in standing wave devices or regenerator in travelling wave devices). A stack is a compartment by means of various linear sub-chambers associated to both ends, heat exchangers are there; one for cold and the other used for hot thermal energy. The sub-compartments are separated through plates whose spatial distance decides region of heat flux caused through the functioning fluid. Working fluid experience expansion and compression since it move along these channels as an effect of the passing of acoustic waves. By providing the accurate wavelength and frequency of acoustic wave, cold heat energy transferred to one surface of stack and hot heat to another, which permit for refrigeration process. Due to advantages like steady-operation, easy construction, and harmless to atmosphere, thermoacoustic refrigeration catch lots of researcher's attention. In recent decades thermoacoustic refrigeration and air conditioning has huge advancement. Also, TAR/engines are useful in waste heat recovery.

At present, thermoacoustic refrigeration is not as highly developed as the vapor compression refrigeration system, which has improved markedly even a century ago its concept developed. Still several stack combinations, different gas mixtures, and various application areas are available for development of thermoacoustic refrigeration systems such as refrigeration appliances, electronic equipment cooling devices, automobile industries, biomedical, food storage, cryogenic, and so on. Thus, in thermoacoustic refrigeration a large amount of scope for innovation is available. Optimization methods as design assist are sternly under-used and rare earlier efforts in thermoacoustic optimization. The idea of using sound waves for cooling gained interest in the 1960s. Even though the physical explanation of this refrigeration technique is simple, analysis of the phenomenon and equations that describe it is not simple. More than the century before thermoacoustic phenomenon was revealed [1] however, merely four decades before important efforts into this field were started at the Los Alamos National Laboratory (Los Alamos National Laboratory is the only laboratory in Los Alamos, N. Mex., USA where classified work towards the design of nuclear weapons has been undertaken besides the Lawrence Livermore National Laboratory), where various sort of thermoacoustic heat engine, refrigerator was developed. In this field, a small amount of other research group are also carrying out there research work such as Acoustic Society of America, Acoustical Society of Australia, ASME, ASHERE, and other National Laboratories, *etc.* On the other hand, the growth of thermoacoustic refrigeration devices is still at beginning phase.

This paper provides brief review of investigations in thermoacoustic refrigeration systems such as investigation associated to design, optimization, and experimentation related to stack, resonator, gas, *etc.*, As well as the growth and the present situation of thermoacoustic refrigeration system. The present work is divided into four different parts, first part is related to methods of optimization (theoretical, numerical, analytical, software, *etc.*), second part is related to stack and resonator tube design, third part is related to gases, and fourth one is sound generation systems in which loudspeaker, amplifier, *etc.* are included.

Review of methods of optimization for thermoacoustic refrigeration system

Various researchers conducted study in thermoacoustic field by using linear theoretical method, numerical method, analytical method, software, *etc.* to optimize the TAR ultimately to improve the coefficient of performance (COP) of systems. Huelsz and Ramos [2] found terminology for phase variation, α, among pressure waves and temperature by using a single-plate, linear theory for thermoacoustic refrigeration phenomenon at ideal situation (endless heat ability and zero Prandtl number for the plate). Piccolo and Cannistraro [3] presented a methodology to explore the source of the divergence from the forecast of the linear theory and compared them with the measured performances of a thermoacoustic device. Tijani *et al.* [4] explained in detail the designing criteria for TAR in order to achieve an optimal system, use the linear thermoacoustic theory to describe design criteria. Dimensionless independent variables were used to decrease the number of parameters and to simplify equations. A method to obtain optimum design for different parts of TAR was established. Based on linear thermoacoustic Sun *et al.* [5] explained optimization on theoretical investigation. A novel Helmholtz resonator was used to advance transportation capability of thermoacoustic engine, which create complete utilization of the interface among compliance and inertance effect. Effect of Helmholtz resonator tube length on outlet pressure amplitude is shown in fig. 2 By means of this arrangement, intensity of output pressure of thermoacoustic engine was augmented as maximum pressure amplitude may be arising at the end of Helmholtz resonator tube. Figure 2 shows the result of Helmholtz resonator tube span on pressure amplitude on exit of resonator tube. Curvatures are for various reservoir volumes. It shows that every curvature hit the highest point on particular length.

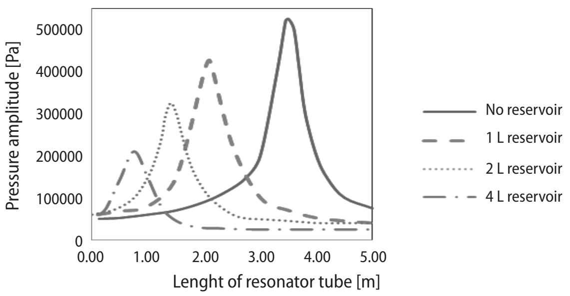

Figure 2. Effect of Helmholtz resonator tube length on outlet pressure amplitude

Highest value decline while reservoir volume enhances. Affected via reservoir, resonator tube length consistent to highest value is much shorter than 1/4 of wavelengths. While no reservoir the output pressure amplitude achieved highest value, which is in fact an acoustic loudspeaker. Although the reservoir volume is 4 liter, the highest amplifying relation is significant. While tube length acquire longer than one wavelength, other pressure magnitude crest come into view occasionally, except with much slighter peak value. Bheemsha *et al.* [6] explained the optimization and design of a thermoacoustic refrigeration system with the help of general linear theory of thermoacoustics, as the basis for the design taking its simplified assumptions into consideration. Optimization was carried out using MATLAB.

Waxier [7] studied the acoustic disturbance theoretically. A complete set of time averaged second-order equations of fluid dynamics of a viscous, thermally conducting fluid between closely spaced parallel plates were solved, when the derivative of the temperature in the absence of the acoustic disturbance with respect to the direction of plate length is not equal to zero. Herman and Wetzel [8] presented a methodology for estimating and designing TAR components to obtain an optimized device. Worlikar *et al.* [9] simulated a thermoacoustic device and numerically investigated the unsteady flow and the temperature field in the vicinity of ideal thermoacoustic refrigeration system. Numerical model simulates energy equation, momentum, and unsteady mass within the thin-plate, and low Mach number boundaries. The variations of COP of apparatus against the heat exchanger length and position were analyzed. Tijani *et al.* [10] described analytical model dealing among solid surface and acoustic wave. Also found thermal-relaxation dissipation when gas is nominal while temperature oscillations within wall following the temperature fluctuation within gas, also concluded that a tube material by means of negligible probable combinations $K\rho C_s$ as well as gas among the principal promising combinations $K_g\rho_g C_p$ could minimize the thermal-relaxation losses. For designing thermoacoustic refrigeration devices Babaei and Siddiqui *et al.* [11] illustrated optimization algorithm and extensive design. The exclusive characteristic of algorithm was its capability to propose thermo acoustically-run thermoacoustic refrigeration system so as to provide feasible refrigeration system.

Heat driven thermoacoustic refrigeration system optimization and design explained by Ghorbanian and Karimi [12] a basic representation was developed which allow to investigating and identifying and the most significant physical characteristics of a dense traveling wave thermoacoustic refrigeration system run via traveling wave thermoacoustic engine. For highest overall COP, the place, hydraulic radius, and length of TAR were optimized. In addition to that COP of refrigerator, prime mover efficiency and dimensionless dissipation of heat and their effect on overall COP are also inspected. Hariharan *et al.* [13] optimized parameters like stack length, stack location, acoustic frequency, and stack plate spacing included in design TAR by means of the response surface methodology. From the results obtained through software DeltaEC, they developed a mathematical model based on response surface methodology.

Parameter related investigation employed to calculate outcome of design considerations on apparatus performance. In [14, 15] exemplified optimization of internal segments of thermoacoustic equipment. Leading closer examination, it was found that the use of DeltaEC to change individual constraint to established best possible design. Lycklama *et al.* [16] illustrated a 2-D CFD simulation study of traveling wave thermoacoustic engine. Raspet *et al.* [17] used the finite difference method to solve the equations of TAR, thermoacoustic engine and Stirling engine, assumed short stack and linear temperature gradient across the stack. Also solved the equations for both standing and traveling wave and compared the results with the measured values. Bheemsha *et al.* [18] explained the design of a resonator and buffer volume for a TAR, modeling was done by using CATIA and optimization of the design was carried out using MATLAB.

The previous mentioned literature is based on optimization methods of TAR which include linear theoretical method, numerical method, analytical, and software method. The linear theoretical method is concentrated only on resonator tube length, pressure amplitude, and plate spacing. Whereas the numerical and analytical methods are used for optimization of mass flow rate of fluid, temperature across the resonator tube, heat exchanger length, heat exchanger position, stack length, frequency of working fluid, stack position, plate spacing, *etc*, with the help of CATIA, MATLAB, DeltaEC software. All this methods are used for optimization of thermoacoustic refrigeration system. Optimization is nothing but the improvement of systems towards better performance; ultimately all this methods are used to improve the COP of thermoacoustic refrigeration systems.

Development of stack and resonator tube for TAR

A long hollow tube is called as *resonance tube* or simply *resonator*, while a solid porous material is called stack. Tijani *et al*. [19] studied outcome of plate spacing and geometry of plate in the stack on the performance of the device. Tried to perfect stack spacing. Also recommended maximum pressure of 12 atmosphere. Earlier, it was found that the refrigerator could sustain about 1.5 atmosphere only. In order to maintain higher pressure and to obtain greater COP, many aspects of the thermoacoustic refrigeration system namely the construction materials used, different array for the stack, *etc.* would have to be altered. The COP thermoacoustic refrigeration system calculated by means of temperature variation along stack, by two dissimilar spacing *i. e.* 0.4 mm and 0.8 mm by Hariharan *et al.* [20]. The analyzed stack segment was prepared by less thermal conductivity substance that is photographic film and Mylar sheet furthermore testing was conducted at 1 MPa pressure by means of helium as functioning fluid. Figure 3 shows time history of temperature and its variation at high temperature end of stack for various stack substance by means of dissimilar plate spacing. Figure 4 presents the graph of temperature variation among cold and hot ends of stack with time.

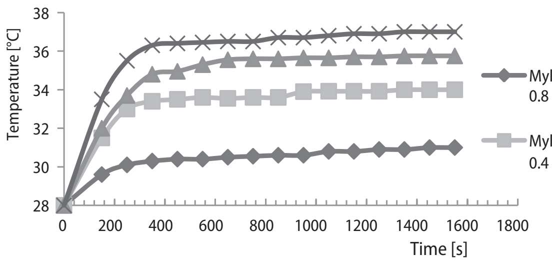

Figure 3. Hot end temperature of the stack *vs.* time for different stack with different spacing

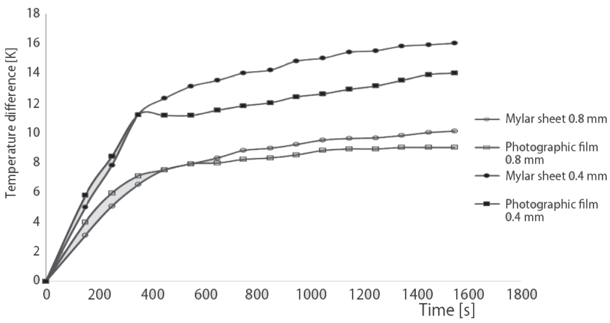

Figure 4. Temperature difference *vs.* time for different stack with different spacing

The effect of stack factor, for instance resonator length, spacing of plate, and thickness of plate, on COP of thermoacoustic engine was calculated by means of pressure amplitude, frequency of resonance and onset temperature variation by means of air as a functioning fluid illustrated by Hariharan *et al.* [21]. Ishikawa and Mee [22] numerically investigated the influence of the stack plate length while spacing of plate is greater than thermal d_k. It was noticed that there was a heat-pumping effect on the long and short plates analyzed with sound standing wave particle displacement length. Further, the energy dissipation close to the plates increased quadratically with the particle displacement, and also found no heat transfer when the spacing of plate was equivalent to thermal d_k. Bassem *et al.* [23] illustrated numerical optimization of regenerator radius and its position, and measured the performance of the optimized refrigerator.

A relationship between size of hot and cold heat exchanger and entropy generation rates in a thermoacoustic device and the temperature differences along the regenerator stack and their location in the resonator explained by Ishakawa and Hobson [24]. It was found that the heat transfer effect is more important than the viscous effect in the quick decrease of the entropy generation. Further, the size of heat exchanger at hot section of regenerator/stack should be smaller as compared to cold section. For various diameters of spherical element of regenerator Biwa *et al.* [25] calculated dependence of phase angle between pressure and displacement oscillations of working gas on refrigerating effect of a Gifford-McMahon refrigeration system. In thermoacoustic refrigeration system to determine the thermal capacity within stack Lotton *et al.* [26] used linear theory. For thermoacoustic pair (The stack of a TAR in the absence of heat exchangers is called a thermoacoustic couple or pair) Babaei *et al.* [27] illustrated modified hypothetical model to include additional practical physical process which was sound dissolution inside the stack, in addition to the heat transfer among stack and its surrounding.

Reid and Swift [28] used a TAR with a steady-flow parallel to the thermoacoustic oscillations passing through the stack, to analyzed numerical studies along experimental outcome for stack temperature profile and the cooling power. In TAR, heat exchanger fluctuating flow heat transport studied [29, 30] Prandtl number, Nusselt number, and Reynolds number utilized to show a relationship outcome of investigation to find a novel relationship for heat transfer within heat exchanger. It was found that by utilizing correlation of transfer of heat for straight flow to design and analysis, considerable inaccuracy can occur. The correlation among variable heat transfer coefficient on heat exchanger, furthermore fluctuating frequency, and mean pressure was explored. If TAR run at significant frequency then the advanced mean pressures resulted in better heat transport coefficients.

Amjadi *et al.* [31] designed and constructed a simple TAR with an adjustable mechanical resonator, coupled with the acoustic resonator. The experimental data showed about 10 % increase in the efficiency of refrigeration in comparison with a simple TAR with no mechanical resonator. Nsofor and Ali [32] constructed a resonator from aluminum tube. To reduce heat loss in conduction, a plastic tube lining placed inside the resonator to check the COP of TAR. Important aspects which manipulate the COP of TAR were recognized. As temperature variation among stack both end was increased, then cooling effect produced also increased, also explained to obtained high cooling load, it was not essential that system had worked on higher pressure. The system should be operated on an optimum frequency and an optimum pressure to obtain maximum cooling load. Figure 5 shows cooling load against temperature variation among stack ends for frequency and stable pressure.

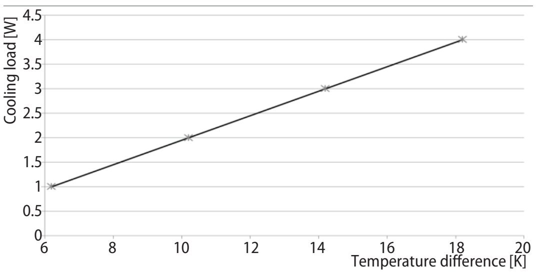

Figure 5. Cooling load versus temperature difference between the ends of the stack for constant pressure and frequency

Both, Wetzel and Herman [33] and Besnoin and Knio [34] discussed in their work thermoacoustic refrigeration system optimization. Wetzel and Herman [33] targeted the best possible COP of a thermoacoustic refrigeration system while Besnoin and Knio [34] targeted heat exchanger. Pressure is one of the adjustable parameters. It has been proved that the temperature difference across stacks can be increased (to a certain extent) by increasing the internal average pressure for helium. Wetzwl and Herman [33] considered fluid characteristics and geometric factors of refrigerator along with a simple algorithm in the direction of to find out the most favorable result. While, managing the working circumstances of thermoacoustic, DeltaEC was utilized broadly.

Paek *et al.* [35] carried out experiments on a working prototype of TAR based on linear thermoacoustic theory which operated heat exchangers with and without water flow. It was found that as soon as the stack temperature contour turns to be non-linear, the COP significantly reduce, that is while TAR functions for given stack length, the temperature range was lesser than best possible value. Hariharan *et al.* [36] designed and fabricated the double thermoacoustic system, fig. 6, generating sound influence with elevated resonance frequency that employed toward run thermoacoustic refrigeration system effectively with working fluid effect and geometrical parameter. As a result of creation of elevated magnitude sound wave, the twin thermoacoustic heat engine has gained significant attention than single thermoacoustic heat engine. By varying the operational fluid, the span of resonator, its COP was analyzed. The performance was measured in terms of onset temperature difference, oscillations pressure amplitude generated from twin thermoacoustic heat engine and high amplitude frequencies. The simulation was performed using DeltaEC software. Figure 7 shows the outcome of operational fluid on initial temperature variation for various resonator spans.

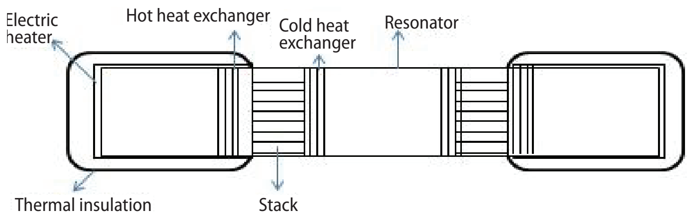

Figure 6. Twin thermoacoustic device

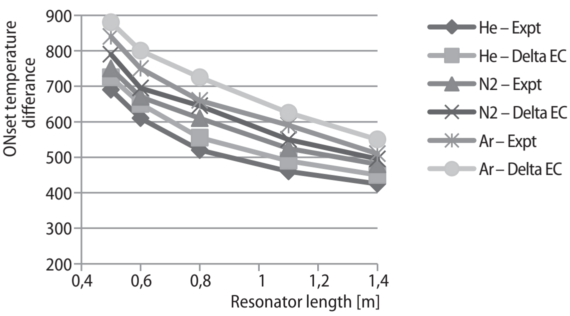

Figure 7. Effect of working fluid on onset temperature difference for different resonator length double thermoacoustic system

Zink *et al.* [37] illustrated the optimization of stack by finite element method considering thermal losses in environment. A easy 2-D computational technique illustrated by Piccolo [38]. While learning entropy formation attributes within central permeable arrangement of thermoacoustic refrigeration system, by this method, standard linear theory equation for thermoacoustic integrates in to energy balance-based numerical calculus method. Mathematically calculated dimensional allotment of time averaged entropy formation rate in adjoining heat exchangers, channel of the stack confirmation as stack-heat exchanger's intersection work as sturdy supply of thermal irreversibility. For a fixed temperature span and refrigerating output level, minimum entropy formation could be efficiently used as an appropriate design test to most favorable stack position, length of stack, and the plate spacing simultaneously was explained.

Various researches on stack and resonator were discussed in the previous literature. The COP of thermoacoustic refrigeration system by the effect of stack geometry, stack plate spacing was discussed. Resonator length, stack plate thickness, effect of stack plate spacing on pressure amplitude, resonance frequency, and onset temperature difference was also discussed. From this literature review it was found that if the spacing between stack plates is increased, the temperature difference was low. Further, if the stack plate spacing reduced then also temperature difference was low.

Gases used in TAR

The international restriction on the use of chlorofluorocarbon (CFC) and doubt over the replacements of CFC give thermoacoustic devices a considerable advantage over traditional refrigerators. Air, xenon, and helium are the gases used in thermoacoustic devices which have no greenhouse effect and are also harmless to the ozone. It is expected that in near future regulations will be tougher on GHG. Awareness about the destructive effects of CFC on ozone depletion and the banning of its production led researchers to find an alternative solution to this problem.

Garrett *et al.* [39] build up novel spaceship cryocooler that utilized inert gas resonant oscillating acoustic wave to transfer heat. It was also utilized within space shuttle discovery. Tijani [40] by utilizing binary gas mixture obtained a low temperature 208 K with TAR analyzed the outcome of various significant factors, like Prandtl number, COP, *etc.* In pulse tube refrigeration system Jin *et al.* [41] studied thermoacoustic phenomenon, with the help of thermoacoustic prime mover to create an acoustic wave to drive the refrigerator. Thermoacoustic prime mover distinctiveness and effect of working fluid *i. e.* helium and different percentage of helium-argon mixture, on the TAR was studied, and during experiments achieved cryogenic temperature of 120 K. From [40, 41] it shows that the thermoacoustic refrigeration system can achieved low temperature, by utilizing working fluid as a helium with other gas mixture and the binary mixtures according to that various lowest temperature was obtained. Sakamoto *et al.* [42] conducted experiments on a TAR contain sound loop-tube with two stacks inside. First stack used as a prime mover and second as a heat pump. Blend of helium gas with air on atmosphere pressure was used as a working fluid. A temperature drop of approximately 289.15 K was observed. Also self-sustained acoustic had advanced harmonics which lowered the performance of the refrigerator.

Dhuley and Atrey [43] investigated the effect of two operating parameters, the resonant frequency and charging pressure on the dynamic pressure inside a TAR, because the dynamic pressure inside a TAR is an important parameter which governs the cold temperature and the cooling power. Tasnim *et al.* [44] did the study on a numerical investigation for increased COP of thermoacoustic refrigeration system by operating conditions as well as the consequence of variant of operational fluid. The thermoacoustic refrigeration system was assessed on the basis of COP, refrigerating effect, and rate of entropy creation in system. Result of deviation of operational fluid by varying Prandtl number was also found. During experiment obtained values of COP 1.53 to 1.7, rate of entropy creation in system 0.1 to 1.5.

The helium gas is non-hazardous, colorless, flavorless, fragrance-free, inert, monatomic gas which leads noble set of gas within periodic chart. It is melting and boiling positions be the lowest between component and it exist merely like a gas apart from some extreme situation. The velocity of acoustic within helium is almost thrice to the velocity of acoustic within air. Since the basic frequency of a gas-packed hollow space is relative to velocity of acoustic within gas, as soon as helium is drawn in, there is consequent raise in resonant frequency of vocal tract. Hence, helium gas is mostly used in thermoacoustic refrigeration as a working fluid. From this literature review it is clear that the researchers have used helium-argon mixture, to increase the performance of TAR.

Use of sound generation systems in TAR

With the help of laser Doppler anemometry Bailliet *et al.* [45] calculated auditory influence flow within thermoacoustic resonator, by measurement of sound pressure via microphone. A fair conformity among investigational and hypothetical outcome was found. Symko *et al.* [46] employed TAR and prime mover to remove heat from an electronic circuit. They drove the thermoacoustic devices at frequencies between 4-24 kHz and investigated the performance of the devices. The COP of a thermoacoustic refrigeration system based on changeable load and compared experimental data with the computed data was experimentally analyzed by Jebali *et al.* [47]. In experiments, stack cold heat exchanger temperature varied while hot heat exchanger maintained on ambient temperature to achieve temperature differences of 0.5 and 10 K. For this temperature variation the refrigerating effect also vary by changing driving frequency between 30 and 65 Hz.

More powerful speaker to obtain more acoustic power and worked on operating frequency to run the device suggested by Zink *et al.* [48]. Acoustic standing wave velocity fields investigated by Siddiqui and Nabavi [49] within rectangular resonator, furthermore consequences of deviation of few refrigerator factors on amplitude of pressure determine. Tang *et al.* [50] explained optimization of standing-wave TAR by the effect of variations in size of acoustic pressure amplifier. Huifang *et al.* [51] investigated the synthetical optimization of acoustic field and hydraulic radius of regenerator that distinguished through relation of traveling wave component to standing wave component (Gp, Gu, Gz, K_x, Φ, *etc.*), COP, temperature gradient, cooling power, and heat flux of TAR by various arrangements of acoustic fields and hydraulic radiuses were also discussed. To optimize COP of thermoacoustic heat engines Trapp *et al.* [52] illustrated a mathematical programming model. Chun *et al.* [53] studied and analyzed acoustic energy and sound waves produced by two identical thermoacoustic lasers (solar power operated high amplitude/high frequency sound wave generator). Microphones and sound pressure level meters engaged for measure acoustic influence on various intervals commencing the aperture for pair of laser of thermo acoustic system for various laser positions. As intervals amplified, it tough to manage the two thermo acoustic lasers in synchronize manner. The phase variation among two thermoacoustic laser result and sound wave amplitudes varied periodically with time, for severance space larger than thrice the diameter of cylinder.

Pan *et al.* [54, 55] did experiment on enforced fluctuation driven through loudspeaker and compared to self-energized fluctuation. Also, an effect of operating frequencies plus power on initial temperature was discussed. It was concluded that compulsory fluctuation had advanced selectivity for operating frequencies. The self-energized fluctuation frequency (fundamental frequency) was best possible option to run thermoacoustic system in realistic appliance. The minimum initial temperature was progressively attained by means of amplify driven energy. Pressure amplitude was principally influenced through initial temperature, minimum initial temperature, then lesser the pressure amplitude. This effort also provided a path to decide driving signal in real life purpose. Also illustrate relation of convection with sound fluctuation by varying driving energy. The temperature and velocity allocation of stack among the cold and hot heat exchangers calculated through thermal infrared imager and particle image velocimetry at 205 Hz, is the resonance frequency of thermoacoustic system. Also suggested that the sound fluctuation have a considerable consequence over convection as well as the heat transmission was improved by perturbation of sound flow.

It is clearly mentioned in the literature that the driving frequency of working fluid is responsible for onset temperature difference and hence on performance of thermoacoustic refrigerator. The pressure amplitude and forced oscillation obtained by powerful speaker. According to requirement of measuring range the microphone pressure measurement device and sound pressure level meter were used for acoustic measurement by the researchers.

Difficulty, advantages, and future of thermoacoustic refrigeration

The major difficulties to utilized thermoacoustic refrigeration

- In current situation of advancement, the COP of TAR is less as compared to VCRS.
- Still TAR does not available commercially.

Main advantages to promote thermoacoustic refrigeration

- Ecological concern and legislation which considerably limit or prohibit utilization of HCFC within less capacity, self-controlled refrigeration appliances.
- Restrictions on flammable refrigerant.
- Improvement and accessibility of TAR which propose effective and cost efficient system over VCRS.

Future prospective of thermoacoustic technology

It observed from former description that major progress has done in stack. Though, the constant advancement in thermoacoustic technology, entire world has increase speed of investigation. So far, it is remarkable that major effort focus on research of stack, resonator and gas, lack of experimental exploration of thermoacoustic refrigeration. Since earlier result attained by researchers, it clearly noticed that a lot of variation among thermoacoustic refrigeration performance with vapor compression refrigeration in terms of refrigeration ability and temperature range.

Outstanding performance of stack and heat transmission is essential

Theoretical investigation point out the actual COP of TAR is based on performance of heat exchanger and stack. Also to make use of stack substance to attain the requisite of perfect stack, still there is room for development in structural design, mechanical design, combination of different stack geometries (thin plates, flat plate with wavy, permeable filled element, honeycomb with circular, wire screens, and so on). Further, the performance of heat transport and flow distinctiveness like fluctuating flow frequency, flow velocity, permeability of stack medium, and inside heat source is necessary to the ability of refrigeration. In conclusion, heat transmits within stack and heat exchangers should be improved to permit the heat produced via thermoacoustic working fluid is transport as early as feasible.

Improvement in resonator and use of different gas is required

The research shows that the performance of thermoacoustic refrigeration system is depend upon the stack, resonator and gas. In most of research work, a constant diameter resonator tube is used, and all researchers are concreted only on resonator tube length, but the effect of convergent-divergent section based on wave velocity is still not considered in resonator tube. By using convergent-divergent section the velocity of gas can be increased, and this will help to used low intensity sound generator which will help in reduce the input power.

In literature review it is found that the most of the researcher's used helium as a working fluid, and determined the influence of operational fluid on initial temperature variation. But effect of various gases such as nitrogen, argon, and different gas mixtures such as helium-argon, helium-krypton, and helium-xenon on cooling load is not studied. The use of convergent-divergent section resonator and gas mixture should enhance the performance of TAR.

Conclusions

This is not an entire listing of most favorable thermoacoustic refrigeration system, whereas it is only a summary of optimization. No doubt each effort is an important contribution to thermoacoustic refrigeration. This supposed not to be assumed optimization in conventional sense, nevertheless its only parametric study. In each possibility, all most favorable design is a local optimum as the optimization execute by each researcher can be considered with only one variable while maintaining other parameters the same. To develop more effective system and decrease price, improvements must be required into stack design, resonator and small but more efficient heat exchanger for fluctuating stream. Furthermore, it necessary to developed an open system which will decrease or eliminate the utilization of heat exchanger plus it will decrease complication and price. The TAR are likely to be lightweight, compact, and contain no harmful refrigerants. These aspects will make it a very appealing option in the future.

Nomenclature

C_p – isobaric specific heat
C_s – specific heat of stack material
d_k – penetration depth
Gp – normalize pressure function
Gu – normalize velocity function
Gz – normalize impedance function
K – thermal conductivity
K_g – thermal conductivity of gas
K_x – wave factor

Greek symbols

ρ – density, [kgm^{-3}]
Φ – leasing phase

Acronyms

CFC – chlorofluorocarbon
COP – coefficient of performance
HCFC – hydrochlorofluorocarbon
TAR – thermoacoustic refrigerator
VCRS – vapor compression refrigeration system

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