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DESIGN OFASAFETY SYSTEMFOR A SOLAR POWEREDDOMESTICELEVATOR

Prof Sankalp K Kulkarni,[1],Prof. S N Jha[2], ProfNitinchandra R Patel[3]

[1,3]Department of Mechanical Engineering, G H Patel College of Engg. and Technology,V.V.Nagar
[2]Department of Physics, Sardar Patel University, V.V.Nagar

Abstract—*The proliferation of science and technology has reduced human efforts in every field. Many of the human activities now rely on technological innovations. The past two centuries have seen a phenomenal improvement in various inventions and discoveries.Same is the case with the first elevator which finds mention in ancient texts to its development in last two centuries. The first commercial passenger elevator was installed by the Otis Elevator Company in 1857 in New York City. It climbed at a then-staggering rate of 40 feet per minute. Today, an Otis elevator in the BurjKhalifa tower in Dubai soars up at a speed of 22 mph. and it didn't even top a new ranking of the fastest elevators in the world from Emporis, a database of construction projects. The list is dominated by elevators located in Asia, including China, Taiwan, and Japan. Japan's Hitachi said Monday it will provide the world's fastest elevators, which can clock speeds of up to 72 kilometers (45 miles) per hour, to a high rise building in China.*

The lift is also used to move other things from one elevation to other. The elevator concerned under the said titleis one which runs on solar power. It is used for just elevation for a single level.Here, it is focused based on design a hydraulic safety system for the specified elevator so that it can move the lift to the ground floor in case of power failure of breakage of rope while making sure that it does not require any power.

Keywords*- Tensile stress, Euler's equation, Cross section area, Nozzle effect*

I. INTRODUCTION

The most accepted lift design is considered to be ropedelevator. In such elevators, the caris lowered and raised by traction ropes of steel rather than to be pushed from bottom. Rope sare connected to lift cage, and loopedona sheave. The sheave is apulleyhav in ggrooves around its circum ference. It holds the hoist ropes, in order that when sheave rotates so do the ropes. An electric motor is connected to the sheave such that when motor moves in one direction, the sheave lifts the lift and viceversa. On the other side of the sheave a counter weight is attached with ropes. It is 40per cent in weight of the fully loaded lift. In case of lift being 40per cent loaded it becomes balanced by the counter weight. Due to this only a little amount of force is required to shift the balance from one side to other. Fundamentally, motor has to overcome friction–the weight on the opposite side does majority of the work. In short, the balance keeps an almost steady potential energy in the arrangement as a whole. Utilizing the potential energy in the lift car (allowing it go down to the ground)develops the potential energy in the counter weight (which ascends to the apex of the shaft) and viceversa. The arrangement is likeasee-saw with equal weights on each side. Guide railson the side of elevat or shaft guide both the lift car and the counter weight. The guide railsmainta in car and counter weight from moving back and forth, and in case of emergency they work with a safety system. The ropedelevat or sare more safe, efficient and versatile as compared to hydraulic elevators.

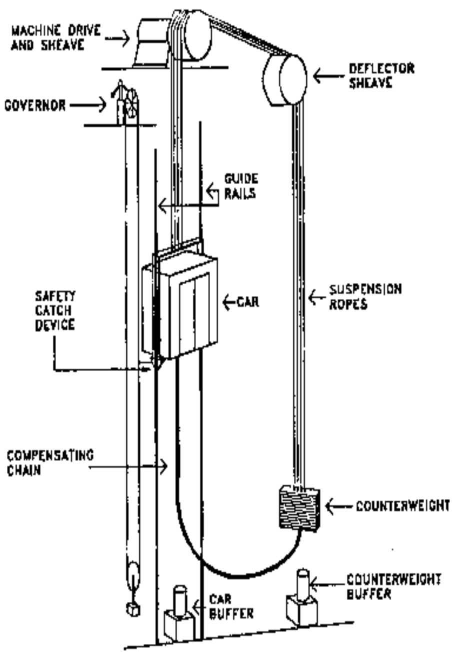

Figure 1. Working of lift

Problem specification

The lift in our subject operates by a solar powered battery with an A.C. supply via an inverter. The lift is primarily used by residents of the house to reach to the 1st floor from ground floor and back. The arrangement of the given lift does not incorporate any provision for a safe descent in case of any emergency viz. Rope breakage or power failure so we have made an attempt to design a hydraulic safety mechanism which does not require any external power source.

II. AQUAINTANCE TO THE LIFT

2.1 Types ofelevators based onhoist mechanism

2.1.1Hydraulicelevators (Push elevators)

Thehydraulicelevatorsrun by thefluiddisplacementwiththepistonasshowninfigure2.The hydraulic fluidinthe cylinder pushesthe pistontorise orfallwhichthenascendsor descendsthe liftcar.Theseliftsaremainlyusedforlowerelevationslikebuildings having2to8floorsand theiraveragespeedbeing200feetperminute.Themachineroomfors uchliftsislocatedatthe lower level.

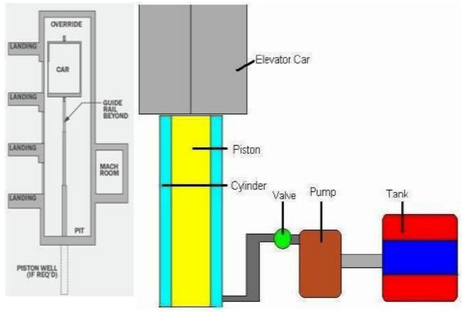

Figure 2. Hydraulic elevator

2.1.2.Pneumaticelevators

They workonthesimplephysicsprincipleofairpressure.Avacuumpump isusedtocreatelow pressureon oneside so that the car moves from the higher pressuresideto the lower pressureside. Andwhenthelowerpressureisincreaseslowlytheliftthenmovesont heoppositeside.Henceit is a simple mechanismwhich does not requireanydiggingor ropes.

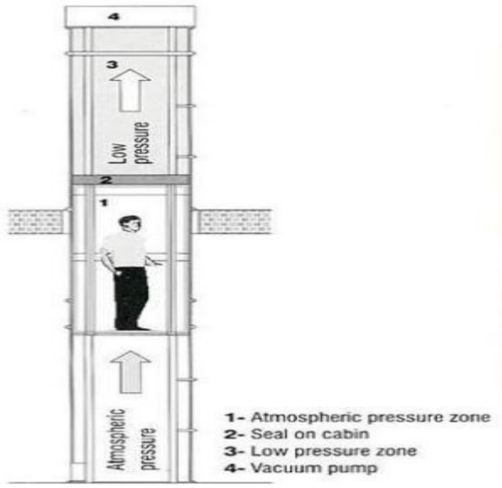

Figure 3. Pneumatic elevator

2.2 Utility of safety mechanism

Elevators have safety mechanisms to lower the risk of the car falling. Traction elevators have cables with counterweights, brakes and devices called governors, which control speed and stop the car if it starts to move too quickly. Elevators have multiple mechanisms to cover for others that break. Hydraulic elevators sit on a platform that rises, so unless the platform fails, the car shouldn't go into a long-distance free fall.

2.3Classification of safety mechanisms

2.3.1 Progressive safety gears

Safety gear functions when the lift car speed exceeds a pre-determined value in the downward direction of the movement of the car whatever may be the reason. It is a mechanical device which grips the guide rails in case of over speed. Two safety gears are attached in the bottom part of car and act simultaneously by a linkage mechanism that is actuated by an over speed governor.

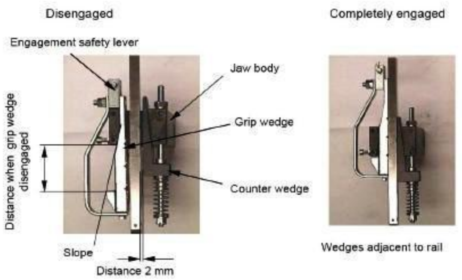

Figure 4. Progressive safety gears

2.3.2Over speed governor

The over speed governor comes into action when the car speed exceeds 115 percent of its rated value and then actuates the safety gear. Typically a rope known as governor rope is linked to thesafeties on the bottom of the car. This rope passes through a pulley at the bottom of the shaft andback up to the machine room and around the governor sheave. In case of over-speeding, the governor grips the rope which then applies the safeties which wedge against the guide rails and stop the car. An over speed governor functions according to floating principle having a cam curve plus roller guided rocker. It may be situated either in machine room or in the head room. The governor has a factory adjusted switch actuates when the tripped speed is met to disengage the machine drive beginning with governor pulley blocking

2.3.3 Buffers

A buffer is a apparatus intended to prevent a descending car or counterweight further than its usual limit and to lessen the force with which the lift runs into the pit for the period of an emergency. It may be of oil type or polyurethane in accordance to the rated speed.

A) Spring Buffer

It is a type of buffer mainly used to cushion the elevator when it lands in the elevator pit. They are used for elevators having speed less than 200 feet per minute or in hydraulic elevators.

B) Oil Buffer

It is a type of buffer used for elevators having speeds greater than 200 feet per minute. It uses oil and springs to cushion the descend of an elevator into the pit Since the pit is prone to water and flooding regular maintenance of the buffer is required.

2.4 Solar powered lift

A solar powered lift is suitable for use in remote areas or where there is lack of power supply but a need of a lift.The lift under consideration in this project has eight solar panels each of 75 watt which generate2.4 KWh per day. That means we can use the lift for 6 hours continuously.The actual operational period for the given lift is is 1 hour / day or 30 to 35 operations to and fro. Hence it can be concluded that the given lift can be used for 5 days in case of a power failure.

2.4.1 Reduction in floor space area

Generally, in the multi-story buildings floor space required for stairs of one floor is 12 ft. x 3 ft. i.e. floor area required is 36 ft2.But this lift requires floor space area of only 4 ft. x 3ft. i.e. 12 ft2 So required floor space in case of elevator is 33% that of floor space required in case of stairs, which means there is a saving of 66% of floor space. So use of lifts in multi-story building is not only helpful in case of restricted space but also cost effective

2.5 Design considerations for hydraulic safety mechanism

2.5.1 Lift going upwards

As the lift moves upwards the piston inside the hydraulic cylinder to be designed will move in upward direction. This will lead to vacuum being generated in the bottom part of the cylinder. So oil will pass from upper portion of the cylinder to the lower via the C-pipe connecting the two halves of the cylinder.

2.5.2 Lift going downwards

As the lift descends the piston inside the hydraulic cylinder to be designed will move downwards. Hence the oil will flow from bottom of the cylinder to the upper part via flow regulatory valve in the second C-pipe in such a way that mass flow rate of oil is maintained . This will enable the lift to reach the ground floor in 35 seconds without consuming any energy.

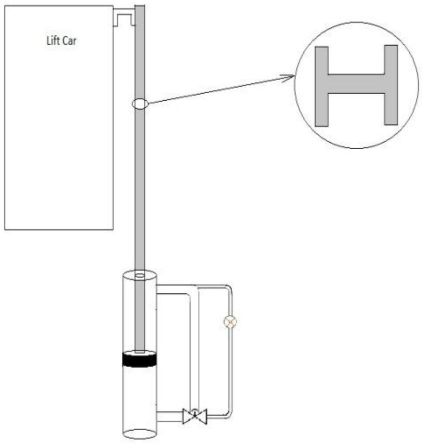

Figure 5. Schematic diagramofhydraulic safetysystem

III. DESIGN METHODOLOGY

3.1 Design of the components of safety mechanism

3.1.1 Design of C-Joint

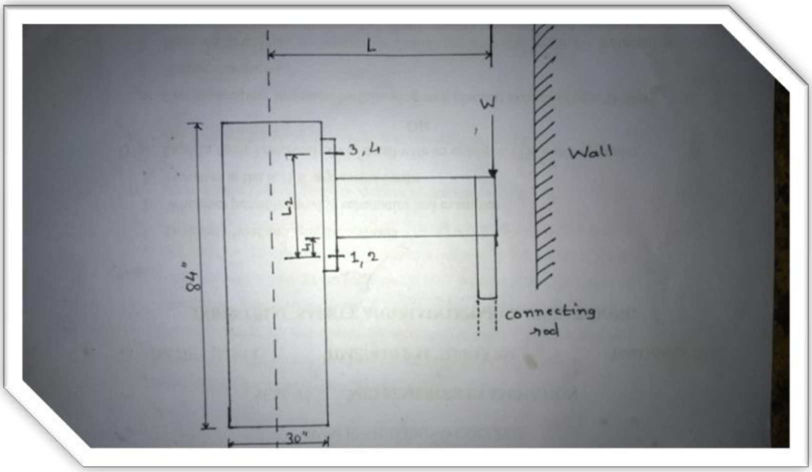

Figure 6. Space availabletodesign C-joint

As shown in the fig. C-joint requires 4 bolts. The calculation for the same is as follows.
Direct shear load on each bolt W_S= (5/4) KN = 1.25 KN.
Tensile load carried by bolt no 3 and 4 will be maximum.
Tensile load Wt = [WxLxL_2] / 2 x [L_1^2+L_2^2]
Where, W = Total Load = 5 kN

L = Distance between load and bolt = 609 mm
Distance between bolt and lower edge = 10 mm
Distance between bolt and upper edge = 40 mm

Now, from the equivalent load due to combined effect of direct shear load and tensile load is given by
Weq = (1/2) x [Wt+ (Wt^2 + $4Ws^2$) $^{(1/2)}$]
Also, from the equivalent load a diameter of bolt can be calculated
Weq = (π/4) $dc^2 \sigma t\ n$
Where, dc = core diameter of bolt

σt= Allowable tensile strength of bolt material (84 MPa)
n = Number of bolts(4)
Core diameter is approximately 84% of the bolt diameter.

3.1.2 Design of Cylinder
Design of cylinder includes the determination of diameter and thickness of cylinder. Diameter of cylinder is arbitrarily determined according to the space between wall and lift.
Let the diameter of cylinder be 60 mm.
For the calculation of thickness the pressure developed inside the cylinder should be computed.
Pressure developed P = W / A,
A = c/s area of cylinder = $(\pi/4)D^2$
t =$(P \text{ x} D / 2 \text{ x } \sigma)$
Since the material used for making cylinder barrel is mild steel SA 36 there maximum tensile stress for this material is 410 MPa
Allowable stress of the cylinder material = 410/FOS = 410/5 = 82 MPa

Figure7. Cylinder

3.1.3 Design of piston
Design of piston includes determination of diameter and thickness of piston. The diameter of piston is same as cylinder dia.The thickness of piston is determined by shear criterion.
W = $\pi \ x \ Dp \ x \ tp \ x \ \sigma s$
W = Total load = 5000 N
Dp= Diameter of piston = 80mm
tp = Thickness of piston
The maximum limit of compressive stress that a mild steel specimen can bear is 407.7 MPa

3.1.4 Design of connecting rod

(a) Solid Circular Section

For design of connecting rod, considering direct and bending stress. Direct stress + Bending stress = Allowable stress

Distance between center line of cage and center line of connecting rod = 609.6 mm)

Moment of inertia of section

Ixx = $(\pi / 64) Dc^4$

Checking the section in Euler's equation for long beam

Critical loadPc = $(n \text{ x } \pi^2 \text{ x E x Ixx}) / l^2$

Where,

n = end fixity co-efficient (Here one end is fixed and one end is hinged so n = 2)

E = modulus of elasticity ($2.1 \text{ x } 10^5$ Mpa)

Ixx = moment of inertia of section

L = length of connecting rod (3657.6 mm)

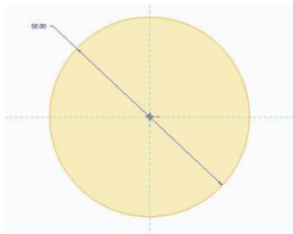

Figure 8. Solid circular cross section

(b) Hollow Circular Section

Direct stress + Bending stress = Allowable stress

Moment of inertia of hollow section Ixx = $(\pi / 64)\,[Do^2 - Di^2]$

Checking the section in Euler's equation for long beam

Critical load $Pc = (n \times \pi^2 \times E \times Ixx) / l^2$

Where,

n = end fixity co-efficient (Here one end is fixed and one end is hinged so n = 2)

E = modulus of elasticity (2.1×10^5 Mpa)

Ixx = moment of inertia of section

L = length of connecting rod (3657.6 mm)

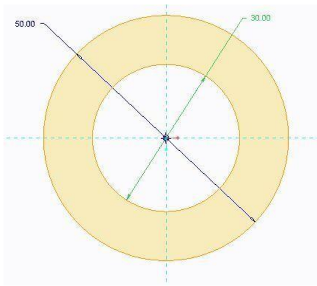

Figure 9. Hollow circular cross section

(c) I -Section

Let t = thickness of flange

B = 3t = width of flange

H= 4t = depth of section

Area A = $8\,t^2$

Moment of Inertia = Ixx = $(176 / 12)\,t^4$

Now, allowable stress in the section should not exceed 280 Mpa

Checking the section in Euler's equation for long beam

Critical load $Pc = (n \times \pi 2 \times E \times Ixx) / l^2$

Where,

n = end fixity co-efficient (Here one end is fixed and one end is hinged so n = 2)

E = modulus of elasticity (2.1×10^5 MPa)

Ixx = moment of inertia of section

L = length of connecting rod (3657.6 mm)

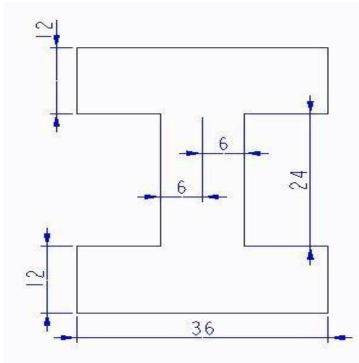

Figure10. I-section

(d) Hollow Square Section

Let, t = thickness of flange

B = 4t = width of flange = depth of section

Moment of Inertia = Ixx = $20\,t^4$

Now, allowable stress in the section should not exceed 280 MPa

Checking the section in Euler's equation for long beam

Critical load $Pc = (n \times \pi 2 \times E \times Ixx) / l^2$

Where,

n = end fixity co-efficient (Here one end is fixed and one end is hinged so n = 2)

E = modulus of elasticity (2.1×10^5 MPa)

Ixx = moment of inertia of section

L = length of connecting rod (3657.6 mm)

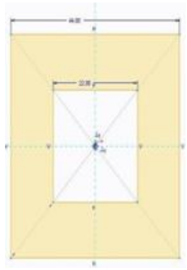

Figure 11. Hollow square cross section

Due to following reasons I-section should be selected.

- High critical load.
- Higher mass moment of inertia in XX direction.
- Material required is less hence less weight.
- Easily available and Cost effective.

Section modulus for I-section is enough as per requirements and material required is less hence weight is less, so, it should be used.

3.1.5Designof pipes

3.1.5.1 Design of pipe-1

For design of pipe-1, our aim is to find its diameter and thickness which will serve its purpose. Now, we know that the diameter of piston is 80mm Since lift travels 11 ft in 40 seconds so its velocity is 11ft/40s i.e. 0.08382 m/s. Length of cylinder pipe is 11.5 ft.And velocity at which piston is coming downwards is known to be 0.08382 m/10sSo, the flow rate 'Q' of the fluid in the piston cylinder will be
Q = Ap x V

Selection of Hydraulic Fluid:
Based on the requirements of the system, with the help of the following graph ISO grade 32 oil is selected.

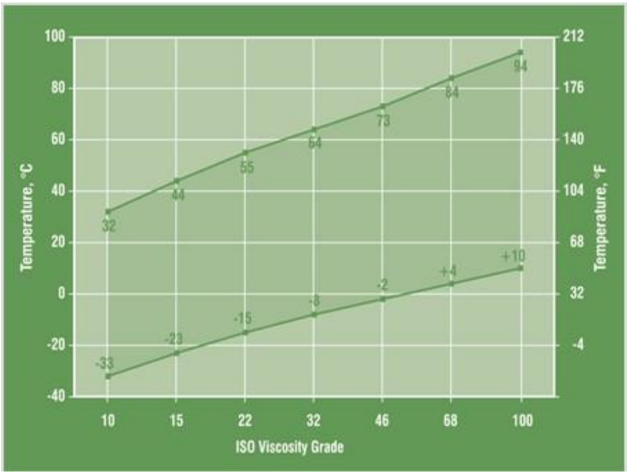

Figure 12. Property variation of ISO Grade 32 oil with temperature

Now, it is known that the for system to incorporate minimal losses, the hydraulic fluid's flow inside the pipe should be laminar.So, deriving first, the condition for laminar flow in pipe 1.
Let the diameter of pipe 1 be d1 and velocity of fluid inside it be V_1. For fluid flow to be laminar, Reynolds's no. should be less than 2040. i.e Re<2040

Reynolds's no. is defined as ratio of inertial force to frictional forces(viscous forces)
Re = ($\rho V1$d1) / μ
So, for flow to be laminar,

2040=(V1*d1)/0.000032
Where, 0.000032 is the kinematic viscosity (μ/ρ in m^2/s) . Therefore V1 * d1 < 0.064
Now, the flow rate of the fluid in the piston cylinder is0.00042111168 m^3/s.

According to the mass conservation, same will be the flow rate in Pipe1.
Therefore, V1x (1/4) x $\pi\ x\ d1$ = is 0.00042111168
Let us assume the diameter of pipe1 to be 20mm.
For thickness of the pipe 1,
Thickness of the cylinder can be computed from the thin cylinder formula.
Thickness t = (P x D1 / 2 x σ)
P=F/A≈1MPa
Where, P = pressure developed inside the pipe
D1= diameter of the pipe
σ = allowable stress of the cylinder material

3.1.5.2 Design of pipe-2

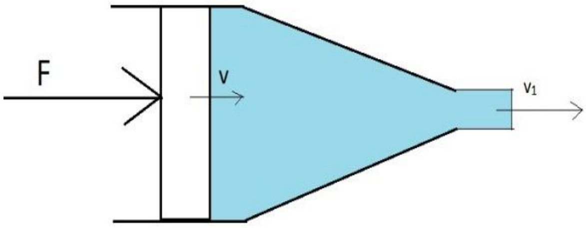

Figure13.Nozzle effect

The concept used in designing pipe2 is shown above. When the fluid passes through the nozzle or any contracting area in the system the change in momentum of the fluid opposes the piston shown above and applies pressure to it. Same concept shall be used in the existing system.

When the fluid travels from cylinder to pipe, there is a slight rise in pressure of the fluid, and then again when the fluid travels from pipe1 to pipe2 again there is a change in momentum. Thus, according to the newton's third law fluid reacts back to the piston and tries to oppose it.Now, for the lift to travel from uppermost position to ground in 30 seconds under emergency(when rope breaks),

Assuming the lift to be stationary when rope fails, Average change in velocity of the fluid in cylinder is (0.08382 – 0) =0.08382 m/s and the time taken by it is 30 seconds. Therefore, 0.08382/30 = 0.002794 N/Kg is the average force on piston due to fluid in cylinder.
Similarly, calculating forces due to change in momentum while entering pipe 1 is 0.004191 N/kg
Like, force due to entering pipe 2 = (V_2 – 1.34112) / 30
Total mass of liquid = $\rho\ x\ V$
By using continuity equation A_1x V_1 = A_2x V_2, diameter of pipe d_2 is found.
Thickness of pipe 2 can be calculated with the similar procedure used in pipe1.

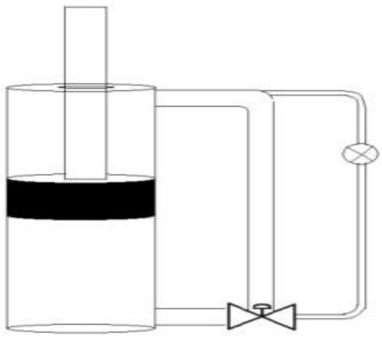

Figure14.Schematic diagram of design of cylinderand flow controllingpipes

CONCLUSION

It has been observed that though there were so many space constraints, we were able to design a safe hydraulic system for safety of the elevator. Here no is required. So, it is cost beneficial and saves space. Also it does not require any other external power sources. The working is safe and design is simple.

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AUTHORS' BIOGRAPHY

Prof. SankalpKulkarni is an Associate Professor in Mechanical Engineering Department of G. H. Patel College of Engineering & Technology, VallabhVidyanagar, Gujarat, India. He did Master degree in Thermal Science in 2004 from M S University, Baroda and Bachelor degree in Mechanical Engineering in 1999 from Jiwaji University, Gwalior. He has total 11 years teaching experience. He presented 1 technical research paper in National conference, 3 in International conference and published 2 in International journals. He is a Life member of ISTE.

Prof. ShreelalNatwarlalJha is R&D consultant & Product Designer by profession. He is Wind mill consultant for CEPT university. He is the owner of Company Supernova Technologies Pvt. Ltd., which manufactures of Gasification Stove (wood stove), Wind Solar Hybrid System, Electronic Security System(Burgalar Alarm) GSM Penal, AutoDial, Solar power system, and having own R & D facility. As an industrialist he has got working experience of more than 15 years. He has got work experience 30 years as a Lab Technicien in Physics Department SP university.

Prof. Nitinchandra R. Patel is an Assistant Professor in Mechanical Engineering Department of G. H. Patel College of Engineering & Technology, VallabhVidyanagar, Gujarat, India. He did Master degree in Machine Design in 2004 from Sardar Patel University, VallabhVidyanagar and Bachelor degree in Mechanical Engineering in 1997 from B.V.M . Engineering College, Sardar Patel University. He has 19years' experience – 5 Years Industrial experience (2 years in Manufacturing and 3 years in Chemical Industries) and 14 years and 10 months teaching experience. He has presented 2 technical research papers in International conferences and published 16 technical research papers in International journals. He reviewed a book published by Tata McGraw Hill in 2012. He is a Member of Institute of Engineers (I) and Life member of ISTE. He is a reviewer / Editorial board of Peer-reviewed journals - International Journal of Advance Engineering and Research Development, International Journal of Application or Innovation in Engineering & Management, International Journal of Research in Advent Technology. He is also recognized as a Chartered Engineer by Institute of Engineers (I) in Mechanical Engineering Division in 2012.