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Power Producing Preheaters—An Approach to Generate Clean Energy in Cement Plants

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Abstract

Demand of cement in developing countries is directly proportional to the development rate of that country. But increasing input cost of cement manufacturing, decreasing margin of profit, scarcity of raw coal availability and emission of greenhouse gases are some constraints, which restrict the growth of cement industry. Hence to combat with all these adverse situations simultaneously, this project report introduces and efforts to generate clean and green energy with the help of combination of preheater tower, which is available in all integrated cement plants and an augmented wind turbine. Hence, the technology is named as "Power Producing Preheaters" or 3P.H. Introduction of 3P.H. in cement industry, generates a definite amount of clean and green energy (as per site conditions), which is directly used in cement production to avoid grid connectivity cost of wind turbine output. Calculations are done to show the overall cost of project, its payback period and reduction in emission of greenhouse gases along with its benefits in cement industry.

Keywords

Wind Energy, Augmented Wind Turbine, Power Producing Preheaters, Clean Energy in Cement Plants

1. Introduction

The manufacturing process of cement consists of mixing, drying and grinding of limestone, clay and silica into a composite mass. The mixture is then heated and burnt into a preheater and kiln, to be cooled in an air cooling system to form clinker, which is the semi finished product. This clinker is cooled by air and subsequently ground with gypsum to form cement [1]. There are three types of process to form cement-wet, semi dry and dry process. In the wet/semi dry process, raw material is produced by mixing limestone and water (called slurry) and blending it with soft clay. In the dry process technology, crushed limestone and raw materials are ground and mixed together without addition of water. The dry and semi wet processes are more fuel efficient. In the wet

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process, 0.28 tons of coal and 110 kWh of power consume to manufacture one ton of cement, where as in the dry process only 0.18 tons of coal and 100 kWh of power consume for the same [1].

Cement consumption rates per capita of different leading countries as per 2008-09 data are—1245 kg for Saudi Arabia, 1040 kg for China, 491 kg for Japan, 378 kg for Russia, 285 kg for United States 271 kg for Brazil and 147 kg for India [1]. These data clearly indicate that growth of per capita consumption of cement indicates the growth of country, which proves that growth of cement industry in any country is directly related to the growth of that country. Hence, encouragement of cement industry is highly needed for development of any country. Growth of per capita cement consumption rate indicates the growth of infrastructure, growth of steel sector along with growth in financial sector also. But the restrictions for cement industry growth are—high input cost of raw material, high power and fuel cost, scarcity of raw coal and emission of green house gases.

Breakup of different costs associated with the production of cement is as follows:

1) Power and Fuel Cost: This cost accounts for nearly 30% of the total production cost. Hence, power and fuel costs have major impact on total operating margin [2].

2) Raw Material Cost: It is the second major part of total cost, after power and fuel cost. Different raw materials used are—limestone, gypsum, silica and fly ash. Raw materials account for 30% - 40% of the cost of sales [2].

3) Transportation Cost: It is the third major part of total cost. Increasing price of crude oil affects the transportation cost. It constitutes more than 10% of the cost of sale [2].

4) Other Miscellaneous Cost: It includes the maintenance cost, manpower cost, inventory cost, marketing and selling cost, etc. In overall, it accounts for 15% - 20% of the total cost [2].

As per above cost break up, it is clear that power and fuel costs have major role in total cost and that this cost drives the total cost of cement production. Fuel is used to heat the kiln of cement plant which is a type of furnace used to burn the material, and amount of fuel depends on the optimization of the process and the type of process used, while power cost is the cost of total power consumed in production of per ton clinker/cement. This cost is also dependent on process optimization and on equipment condition that is maintenance of equipments. Most of the cement plants use thermal power for cement production (burning of coal) due to which green house gases generate which is responsible for the global warming *i.e.* depletion of ozone layer and hence responsible for climate change.

Hence to combat with above mentioned restrictions *i.e.* to reduce the power cost and reduction in emission of green house gases, in production of cement, this project introduces a new technology named as "Power Producing Preheaters" *i.e.* "3P.H.", which introduces generation of clean and green energy up to a definite amount (as per site conditions) for cement production with the combination of preheater tower, available in all integrated cement plants and augmented wind turbine.

2. Introduction of Wind Power

Wind is air in motion. It is generated due to earth's rotation due to which there is uneven heating of earth's surface by sun rays. The sun rays cover a much greater area at the equator and smaller area at the poles. Hence the hot air rises from the equator and expands towards the poles, which causes wind. Wind has mass and mass in motion has a momentum, which is a form of energy that can be harvested through a wind turbine. A wind turbine is a system which transforms the kinetic energy available in the wind into mechanical or electrical energy that can be used for any required application.

2.1. Advantages of Wind Power

Lots of advantages of wind turbine or wind power are clearly visible. Some of them are—one time installation cost, low operational and maintenance cost, no fuel cost, environment friendly and pollution free, lowest gestation period, limited use of land. In all above advantages the most important is zero emission of green house gases which is the most needed step for current scenario to avoid climate change.

Power (theoretical) in the wind can be expressed as [3]

$$P_{wind} = \frac{1}{2} \times \rho \times A \times V^3$$

where: P_{wind} = Theoretical power in the wind (w/m^2).

ρ = air density (kg/m^3).

A = swept area or projected area (m^2) (Wind turbine rotor area).

V = average wind speed towards turbine blades (m/s).

In 1919, the physicist, Albert Betz showed that from an ideal wind turbine, maximum kinetic energy conversion limit is 16/27 *i.e.* 59.3% of the kinetic energy of wind to be capture. This is known as Betz limit or Betz law and can be used in any wind turbine. Since this is the maximum limit of kinetic energy conversion hence in any case of modern wind turbine design, the practical limit may reach up to 70% to 80% of the theoretical limit.

Hence in actual power obtained from the wind turbine can be expressed as

$$P_{wind} = \frac{1}{2} \times \rho \times A \times V^3 \times Cp \quad [3]$$

where: P_{wind} = Power in the wind (w/m^2).

ρ = Air density (kg/m^3) = 1.225 kg/m^3.

A = Projected area or wind turbine rotor are (m^2).

V = Average wind speed (m/s).

Cp = Coefficient of efficiency.

$$Cp = \eta_m \times \eta_e \times \eta_{aero} = (0.57 - 0.45)$$

where: η_m= Mechanical efficiency.

η_e = Electrical efficiency.

η_{aero} = Aerodynamic efficiency.

2.2. Typical Arrangement of a Wind Turbine

The conversion of wind energy to useful energy involves two processes. The primary process of extracting kinetic energy is from the wind and conversion of mechanical energy at the rotor axis. In the secondary process, the conversion of rotor's mechanical energy into useful energy carried [3].

ROTOR → GEAR BOX → GENERATOR → OUTPUT

Practically the power obtained by a wind turbine [3] is given as

$$P_{wind} = k \times \frac{1}{2} \rho \times A \times V^3$$

where: $K = C_P N_G N_B$.

C_P = Coefficient of performance of kinetic energy extraction = 0.593= $\frac{16}{27}$ = Betz limit.

N_g = Generator efficiency.

N_b = Gear box/bearing efficiency.

- The torque generated by the wind turbine is

$$Ts = \frac{P}{W_s}$$

Ts = Mechanical torque at the turbine side.

P = Power output of the turbine.

W_s = Rotor's speed of the wind turbine.

- The power coefficient Cp is the percentage of power in the wind that can be converted into mechanical power and the ratio of the blade tip speed to the wind speed is referred as the TIP-SPEED RATIO (TSR)

$$TSR = \frac{W_s}{v} \times R \quad [3]$$

R = Radius of the wind turbine rotor. Since

$$P_{wind} = k \times \frac{1}{2} \rho \times A \times V^3 \quad [3]$$

where k is a constant. Hence, wind power output depends on.

2.3. Density of Air

Density of wind varies with temperature as

$$\rho\left(\text{kg}/\text{m}^3\right) = \frac{353.12}{273.15 + \text{T}} \quad [4]$$

Generally it is counted as 1.225 kg/m^3 at sea level. Since it is directly proportional to wind power, hence play a role in output power. But the value of density is as low as it does not important (impact) on the total power generated by wind turbine. Density depends on temperature of air and elevation or height of air from sea level. From the above relationship it is clear that as the temperature increases air density reduces and wind power output also reduces. The maximum air density is at the earth's surface. Air density decreases with height away from the surfaces of earth as the pull of the earth's gravity is less.

2.4. Wind Power Density

Variation in wind power density also affects the wind power output. It is directly proportional to the wind power output. Wind power density is dependent of air density and height of location as

$$\text{P}_2/\text{P}_1 = \left[\text{h}_2/\text{h}_1\right]^{3/7} \quad [4]$$

From above, it is clear that wind power density increases with height of the turbine rotor.

2.5. Turbine Swept Area (TSA)

Turbine swept area or diameter of the rotor blades is directly proportional with wind power output. Wind power output is directly proportional to T.S.A which is directly proportional to (Rotor Diameter)^2. TSA is a part of rotor design which includes following considerations Blade length, Blade number, Blade pitch, Blade shape, Blade material, and Blade weight etc

The design of the blades used is based on blade element theory and on Betz equation. Drag powered wind turbines are characterized by slow rotational speed and high torque capabilities, while the lift powered wind turbines have much higher rotational speed than drag types and therefore are well suited for electricity generation.

2.6. Angle of Attack (Blade Angle)

Practically blade angle can vary in between 1.0 to 15.0 degrees.

2.7. Blade Number

Generally aerodynamic efficiency increases with the number of blades but with diminishing return. The fewer the number of blades, the lower the material and manufacturing cost will be. Higher rotational speed reduces the torques in the drive train, resulting in lower gear box and generation costs. Turbine with many blades or very wide blades will be subjective to very large forces when the wind blows at a critical fast speed.

2.8. Tip-Speed Ratio (TSR)

The Tip-Speed ratio is the ratio of the rotational speed of the blade to the wind speed. The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed. Electricity generation requires high rotational speed. Lift type wind turbines have maximum TSR of around 10 while in drag type turbine the TSR is approximately 1.0.

2.9. Wind Velocity

Wind power output is directly proportional to third power of velocity of wind striking on rotor. Hence doubling the wind velocity will result in eight times power output.

2.10. Blade Shape

The speed with which the tip of the rotor blade moves through the air is known as tip speed. At the tip of the blades the speed is some 8 times higher than the speed of the wind, hitting the front of the turbine. Hence rotor blades for wind turbine are always twisted.

2.11. Rotor's Height

Since wind power output is directly proportional to third power of wind velocity, and wind velocity increases as per 1/7th law at height, hence height of turbine rotor is another important parameter for turbine output. As per 1/7thlaw of wind velocity, which is also known as 1/7th power law to get the wind velocity at any altitude

$$\frac{V_2}{V_1} = \left[\frac{Z_2}{Z_1}\right]^{\frac{1}{7}} \quad [4]$$

The energy in the wind increases with the cube of the wind speed (P directly proportional to V^3) and wind speed increases with height. An increase of just 26% in wind speed means twice as much power available in the wind, and the turbine till produce almost twice as much. Double the wind speed and almost eight times power output we will get.

2.12. Conclusion for Wind Power

As we discussed above, and from wind power output equation

$$P_{wind} = k \times \frac{1}{2} \rho \times A \times V^3 \quad [3]$$

We can conclude that wind velocity and turbine rotor's area are the two important parameters to increase the wind power output. Since wind velocity increases as per 1/7th law with respect to height, hence height of turbine rotor is also a critical parameter to increase the wind power output.

3. An Emerging Technology for Modern Wind Turbines (Augmented Wind Turbines)

Energy obtained from wind is proportional to the cubic of wind speed and hence a small increase in wind speed will result in a large magnification or augmentation of the wind energy. Hence the modern wind turbines are augmented in such a way to increase the wind speed of turbine's rotor to a required value. Now we will discuss about the same design of wind turbine.

To increase the wind turbine output, by increasing the wind velocity, is considered by introducing the ducted wind turbine, which will use the equation of continuity as per **Figure 1**.

$$A_1 V_1 = A_2 V_2 \quad \text{or} \quad V_2 = \frac{A_1 \times V_1}{A_2} \quad [5]$$

where A_1 = Area of intake.

V_1 = Velocity of air flow at intake.

A_2 = Cross sectional area at venturi.

V_2 = Velocity of air at venturi.

Construction of such a wind turbine will be such as turbine's rotor will be placed in an augmented or ducted path at venturi so that to utilize the augmentation in velocity (V_2).

As the power extracted from wind has a cubic relationship to wind velocity and linear relationship to pressure, this is exploited in the ducted turbine and given an advantage of a factor nearly 17 (improvement factor) over the conventional turbine in theoretical calculations, not including coefficients of power transformations.

To reduce complexity of design in the augmented wind turbine, controlling angle of attack is not built in to the turbine blades , as with conventional wind turbines . The ducted turbine uses Variable Inlet Guide vanes (VIGV́S) mounted in the air stream prior to the turbine rotor, which controls angle of attack maintaining optimum performance, while the mechanism do not have to be mounted in confines of a hub. An annular arrangement is proposed that houses the pitch change mechanism in the nacelle as inner ducting reducing inertia on the rotating mechanism.

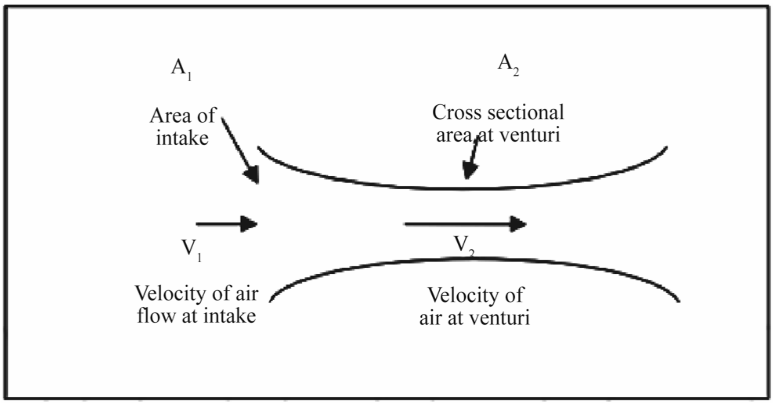

Figure 1. Wind turbine augmentation [5].

$$\text{Since} \quad V_2 = \frac{A_1 \times V_1}{A_2} \quad [5]$$

Hence from above it is clear that by placing the wind turbine inside a convergent duct, we should see increased efficiency as the air flow is accelerated through the venturi. Gains will also be made with reduction of span wise flow and the elimination of blade tip vortices. Accordingly six percent reduction in drag can be gained by the elimination of blade tip vortices.

3.1. Comparison of Wind Turbine Output with and without Augmentation

3.1.1. Without Augmentation

No ducting is used in such condition, as shown in **Figure 2**. Turbine diameter is set as 3 meter with an unusable hub diameter as 250 mm and wind velocity as 6 m/sec and considering the un useful hub diameter in both cases we get

$$A = \frac{\pi}{4} = (3.14/4) \times (3 - 0.25)^2 = 5.936 \text{ m}^2$$

Hence Power obtained will be

$$\begin{aligned} P &= \frac{1}{2} \times \rho \times A \times V^3 \\ &= \frac{1}{2} \times 1.293 \times 5.936 \times 6^3 \left(\text{air density} = 1.293 \text{ kg/m}^3\right) \\ &= 828.93 \text{ Watt} \end{aligned}$$

3.1.2. With Augmentation

A ducted wind turbine with acceleration of air flow due to the venturi effect aligned with Bernoulli's equation of continuity is shown in **Figure 3**.

All the set parameters are fixed as in previous case while dimensions of ducting at venturi and intake are set as 3.0 meter and 4.5 meter.

Now

$$A_1 = \frac{\pi}{4} d_1^2 = 3.14/4 \times (4.5)^2 = 15.896 \text{ m}^2$$

$$A_2 = \frac{\pi}{4} d_2^2 = 3.14/4 \times (3 - 0.25)^2 = 5.936 \text{ m}$$

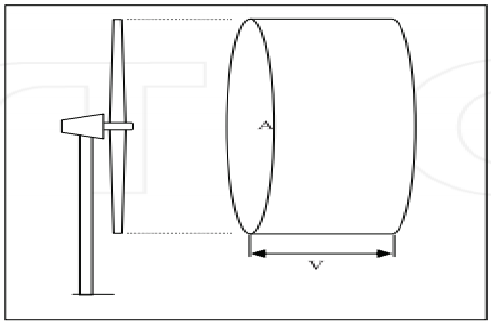

Figure 2. Wind turbine without augmentation [5]. (A ducted horizontal wind turbine for efficient generation. I. H. Al-Bahadly and A. F. T. Petersen, Massy University New Zealand).

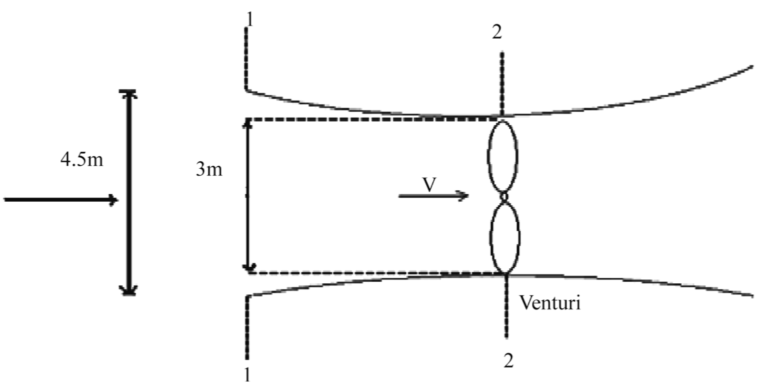

Figure 3. Wind turbine with augmentation [5].

Using

$$A_1V_1 = A_2V_2 \quad \text{or} \quad V_2 = \frac{A_1 \times V_1}{A_2}$$

Or,

$$V_2 = \frac{15.896 \times 6}{5.936} = 16.066 \text{ m/sec.}$$

If we look at the relationships between the factors of the power eq^n, we notice a linear relation between density and power, where as there exists a cubic relation between velocity and power. This will be exploited with the ducted turbine design. The density will be affected by the acceleration of the air flow due to the venturi-effect. To investigate the change in density to the air flow, we must assume dry as being an ideal gas, then apply the ideal gas law equation:

$$P_a \times V_g = nRT \quad \text{(Ideal gas equation)}$$

where

P_a = Pressure,

V_g = volume of gas,

N = number of kilo moles,

R = gas constant,

T = Temp. In Kelvin,

m = mass.

If we consider the density of air as:

$$\rho = \frac{m}{Vg}$$

Then from above equations, we can calculate the density of air in the turbine:

$$\rho = \frac{n \times Pa}{R \times T}$$

If we consider, the minimum pressure gradient as 101,221 Pa then from above equation we can calculate the density drop in air flow through the duct. Using equation as:

n = 29 kg/kilo mol.

P_a = 101,212 Pascal

R = 8.314 J/K/mol

T = 293 K

Hence, $\rho = \frac{29 \times 101221}{8.314 \times 293}$ or ρ = 1.205 kg/m^3

While density of air at standard temperature and pressure is ρ = 1.293 kg/m^3

$$\text{Hence \% change in density} = \frac{1.293 - 1.205}{1.293} \times 100 = 6.80\%$$

Hence considering the change in air density (1.205 kg/m^3) and calculating the power output as

$$P = \frac{1}{2} \times \rho \times A_2 \times V_2^3$$

$$P = \frac{1}{2} \times 1.205 \times 5.936 \times (16.06)^3 = 14{,}821.3362 \text{ Watt}$$

Hence augmentation obtained = 14,821.3362/828.93 = 17.88

This proves the increase in efficiency from a ducted wind turbine. The calculations proves an increase in efficiency of a factor of 17, from the same ambient wind velocity of 6 m/sec and includes the reduction in density as the air accelerates through the venturi, and idol diameter of hub too.

This significant increase in efficiency can be exploited in a number of ways, either to make more money with the same size diameter turbine or to make the turbine smaller which is more desired for our purpose.

4. Introduction of Power Producing Preheaters (P.P.P.H.) in Cement Industry

As we discussed in previous topics that power generated by a modern ducted wind turbine, mainly depends on

- Wind velocity.
- Turbine swept area.
- Air density.
- Augmentation used.

Since wind velocity increases with height or altitude from ground or sea level, hence it is the function of height from the ground. Turbine swept area or rotor diameter is a design parameter and depends on site condition and installation and fabrication cost. Air density has very less effect on wind turbine output. Augmentation used is also a design parameter which helps to reduce the rotor size and to increase the wind velocity to a desired value. From all these facts we can conclude that the favorable conditions for better wind power output are as follows:

- Obstacle and turbulence free wind flow.
- High altitude.
- Optimum augmentation.
- High average wind speed.

Now considering about a cement plant. Generally in all integrated (Complete) plants, following properties, which are very much favorable to install a ducted wind turbine, are observed

- Situated far away from urban area.
- A preheater cyclone tower of reinforced cement concrete (R.C.C) with overall height range 80 - 130 meters as shown in **Figure 4**.
- Necessary supporting structure to install a ducted wind turbine for augmented performance of turbine.

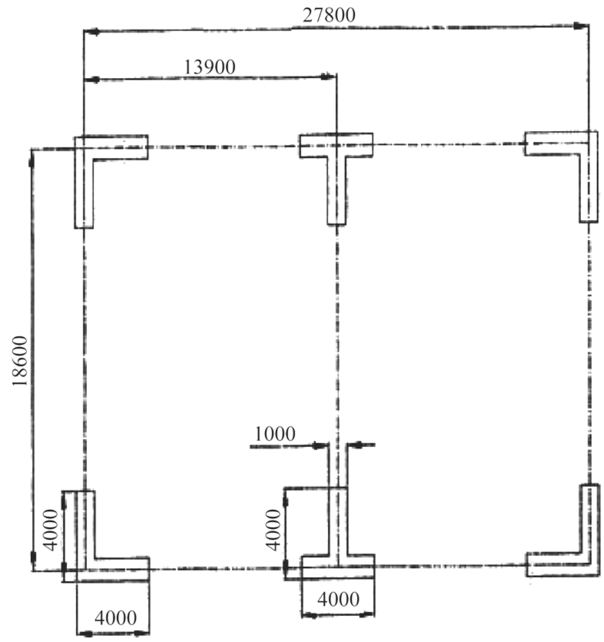

Figure 4. Typical plan (top view) of R.C.C preheater tower in cement plant. (All dimensions are in mm).

These entire favorable conditions offer us to introduce the concept of Power Producing Preheaters *i.e*. 3P.H.in cements plants. The structure of such a ducted wind turbine will be installed on preheater tower top roof i.e. at 80 - 130 meter height above from the ground to utilize $1/7^{th}$ law of wind velocity. Augmentation used increases the average wind velocity near rotor hub i.e. near venturi and r.c.c structure of 80 - 130 meter height will reduce the fabrication cost of wind turbine tower structure. Use of such an augmented turbine will have following visible advantages.

4.1. Utilization of $1/7^{th}$ Law of Wind Velocity

As per this law

$$V_1/V_2 = (H_1/H_2)^{1/7} \quad [4]$$

Generally in all integrated cement plants, we have an r.c.c (reinforced cement concrete) cyclone preheater tower of 80 - 130 meter height, of material composition M20/M30 while top slab thickness is 200 - 300 mm, is available. Now considering the average standard wind speed at any site as 4 m/sec (which is measured at 10 meter height above the ground) and height of rotor above the ground level from top slab is 100 meter, then

$$V_2/V_1 = (H_2/H_1)^{1/7}$$

Or,

$$V_{100}/V_{10} = (H_{100}/H_{10})^{1/7} = (100/10)^{1/7}$$

Or,

$$V_{100}/4 = (10)^{1/7} = 1.3895$$

Hence

$$V_{100} = 5.558 \text{ m/sec}$$

Hence, the 4 m/sec wind velocity converts into 5.558 m/sec wind velocity. This magnification is very important as it reduces the requirement of big diameter rotor and hence reduces the total cost and load on preheater tower also. Similarly we can calculate the power density amplification as

$$P_2/P_1 = (H_2/H_1)^{3/7} \quad [4]$$

4.2. Introduction of Augmented Wind Turbines

As we saw that ducted wind turbine increases the wind power output nearly 17 times, hence this magnification in total output power is very important to reduce the rotor size and hence its fabrication cost. Ducted turbine works on the principle of equation of continuity as shown in **Figure 1**

$$A_1 V_1 = A_2 V_2 \quad [5]$$

where A_1 and A_2 are area of duct at any two places while V_1 and V_2 are the velocities of wind at these two points respectively **Figure 1**. Due to this principle we can change or get the desired wind speed at turbine's rotor which in turn gives the opportunity to reduce the rotor diameter because installing a large diameter rotor will not be suitable for tower top in cement plants. Hence using ducted wind turbine the rotor diameter can be kept as minimum as required. Along with this, another important advantage of using ducted wind turbine is availability of wind in a unique direction. As we know that ducts of augmented wind turbines use the variable inlet guide vanes to guide the outside wind to rotor's direction, hence any change in the direction of wind will cause no effect on the turbine.

Inlet guide vanes and stators have been incorporated into the design of ducted wind turbine to ensure that air flow is offered to the turbine at an optimum angle of attack. For any airfoil cross section to be efficient, it has to be offered to the air flow at the optimum angle of attack.

4.3. Low Cost Wind Turbines

Another and equally important advantage of installing a wind turbine on preheater tower top is low cost wind energy. As we know that installing a ducted wind turbine at a high altitude is always favorable, but the fabrication cost of wind turbine tower will increase so much on high altitude that it will not be economical to install. Hence using the r.c.c preheater tower's height for wind turbine tower installation on its top, will reduce almost 60% - 70% cost of turbine tower fabrication cost. On the other hand since nearly 11% cost of total cost belongs to grid connection cost, hence using wind turbine output for cement production will eliminate this 11% cost of total cost [6]. The cost break up of total installation cost wind turbine is as follows

Wind turbine fabrication cost (64%)
Grid connection cost (11%)
Planning/Miscellaneous cost (9%)
Foundation cost (16%)

From the above mentioned table of break up cost for installation of wind turbine, it is clear that 11% of total cost includes grid connection cost while 26.3% of total turbine fabrication cost includes in wind turbine tower fabrication [6]. Hence installing a ducted wind turbine on preheater tower top will reduce this 26.3% cost of turbine tower fabrication and 11% of total cost is reduced by using the generated power in production of cement itself. Both these cost will make a major relief in installation cost per MW.

5. A Typical Case Study for Introducing Power Producing Preheaters in Cement Plant

Consider an r.c.c cyclone tower of preheater with certain dimensions as per a particular site. The plan *i.e.* top view and the dimensions this preheater tower is shown in **Figure 4**. Typical parameters and dimensions of this preheater tower are as follows

- Breadth of preheater tower = 18.6 meter.
- Height of top slab from ground = 100 meter.
- Width of preheater tower = 27.8 meter.
- Average wind speed recorded at site = 4 m/sec = V_{10}.

Considering 30 meter hub height from tower top slab, hence overall height of wind turbine rotor from ground = 100 + 30 = 130 meter.

Considering dimensions of prepared duct, as shown in **Figure 6**.

- Diameter of duct at venturi = d_1= 15 meter.
- Diameter of duct at opening = d_2 = 30 meter.

Hence, the final structure of such wind turbine is shown in **Figure 5** as below.

- Average wind density = 1.25 kg/m^3 (considering reduction in density at venturi).

Now using 1/7 th law of wind velocity at high altitudes, we have

$$V_{10} = 4 \text{ m/sec}, H_{10} = 10 \text{ meter}, H_{130} = 130 \text{ meter}, V_{130} = ?$$

Hence using 1/7 th law

$$V_{130}/V_{10} = \left(H_{130}/H_{10}\right)^{1/7}$$

Or,

$$V_{130}/4 = \left(130/10\right)^{1/7} = \left(13\right)^{1/7} = 1.442$$

Hence

$$V_{130} = 4 \times 1.442 = 5.768 \text{ m/sec.}$$

Hence, wind speed at rotor's height = 5.768 m/sec

Now using equation of continuity for prepared duct as in **Figure 6**

$$A_1V_1 = A_2V_2$$

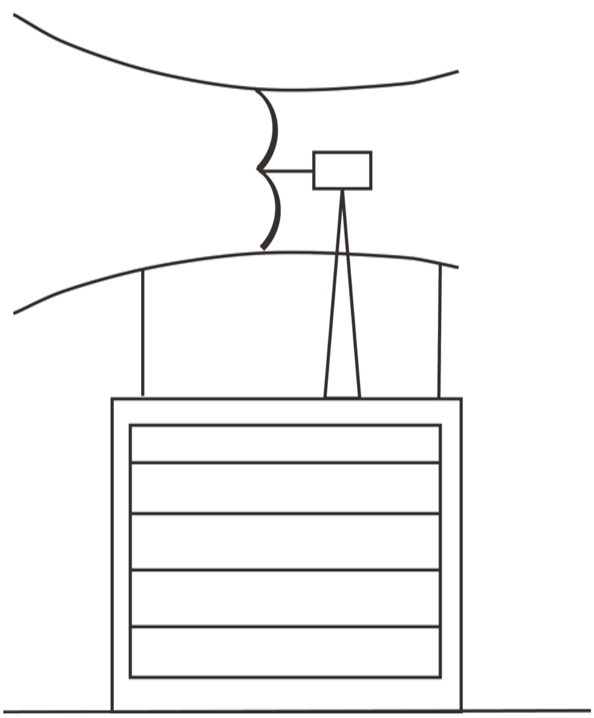

Figure 5. Complete technology of 3P.H.

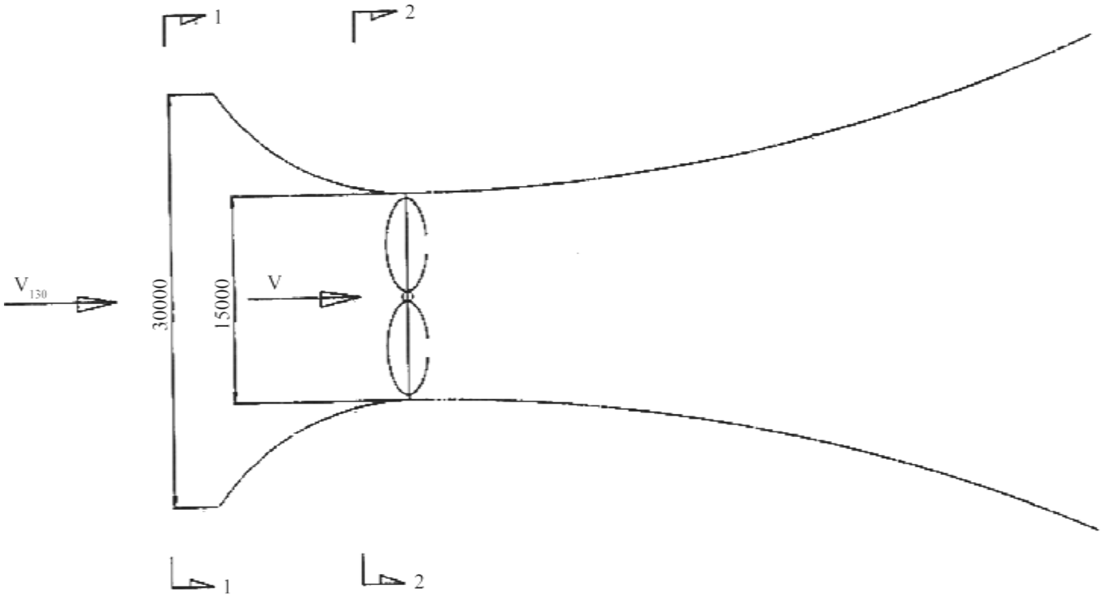

Figure 6. Dimensions of ducting (all dimensions are in mm).

Here

$$A_1 = \frac{\pi}{4} d_1^2,\ d_1 = 30 \text{ meter}$$

$$V_1 = V_{130} = 5.768 \text{ m/sec}$$

$$A_2 = \frac{\pi}{4} d_2^2,\ d_2 = 15 \text{ meter}$$

$$V_2 = \text{velocity at venture} = ?$$

Hence

$$A_1 V_1 = A_2 V_2 \quad \text{or} \quad \frac{\pi}{4} d_1^2 \times V_1 = \frac{\pi}{4} d_2^2 \times V_2$$

Or,

$$(30)^2 \times 5.768 = (15)^2 \times V_2$$

Or,

$$V_2 = 23.072 \text{ m/sec.} = \text{Wind speed at rotor's hub}$$

Now we will calculate the maximum power obtained from these parameters and dimensions of wind turbine, taking considerations of Betz limit of maximum power conversion as 16/27 and considering all efficiencies including mechanical, electrical, and aerodynamic efficiency. Hence overall efficiency

$$C_p = \text{Betz limit} \times C_{mech} \times C_{elec} \times C_{aero} = 16/27 \times 0.96 \times 0.95 \times 0.96 = 0.5188$$

For safety consideration taking this overall efficiency = 0.50.

Hence, maximum power obtained from such an augmented wind turbine is

$$P_{max} = \frac{1}{2} \times \rho_{air} \times A_{rotor} \times V_{rotor}^3 \times Cp$$

$$= 1/2 \times 1.25 \times 3.14 \times (15)^2 \times (23.072)^3 \times 0.50$$

$$= 671561.367 \text{ Watt} = 671.562 \text{ kW}$$

Hence

$$P_{max} = 671.562 \text{ kW}$$

6. Some Results and Discussion

As per the study report of CEA (Central Electricity Authority of India) [7], based on the study of 105 thermal plants in India of more than 100 Mw capacity each with total installed generation capacity of 93,172 Mw, the combustion technology in these 86 plants is based on pulverized coal burning but the type of furnace technology design of the boiler, forced draught fans etc differ with plants. Based on CEA data (2010), specific coal usage at 03 plants is less than 0.6 kg/kWh, at 19 plants usage is between 0.6 - 0.7 kg/kWh, at 07 plants usage is between 0.9 - 1.0 kg/kWh and at 03 plants usage exceeds 1.0 kg/kWh. In most general cases, specific fuel usage lies in between 0.7 - 0.9 kg/kWh *i.e.* on average 0.8 kg/kWh. In the same report of CEA, we know that emissions per unit of electricity are estimated to be in the range of 0.91 - 0.95 kg/kWh for CO_2, 6.94 to 7.20 gm/kWh foe SO_2 and 4.22 to 4.38 gm/kWh for NO, during coal consumption for electricity generation [7].

Hence keeping in mind about these facts, the effects and advantages of introducing Power Producing Preheaters technology in cement industry can be conclude as.

6.1. In Terms of Cost

As we know that cement industry is continuously struggling by high input cost of raw material and high power cost. With the use of 3P.H. we are trying to reduce the power cost for cement production.

We know that in modern cement plants, power consumption of per ton cement manufacturing lies in the range of 90 - 100 units per ton of cement production [1], while through grid it costs nearly 5.50 INR/unit [7], (INR = INDIAN NATIONAL RUPEE) and CPP costs nearly 4.0 INR/unit. Considering lowest cost per unit *i.e.* INR 4.0 per unit, then we are investing INR.380 per ton of cement. Let's take the example of a cement plant of capacity 2.0 MTPA delivering 5556 M.T of cement per day. Hence total investment in power will be around 5556 × 380 = 2,111,280 INR per day (USD 32481 per day) (USD = US Dollar, 1 USD = 65 INR).

Now the wind turbine installation cost in present scenario is nearly INR.70 million per Mw (USD 1,076,923 per mw) While our output is 671.562 kW. Further we are saving our cost by eliminating grid connection cost and tower fabrication cost by 11% and 23% respectively. Hence accounting all these reduction our cost of installation comes at 42.35 million INR (USD 651,538.45) for installing 672 kW (671.562 = 672 approx) capacity ducted wind turbine on preheater tower top, which will be one time investment for company.

Hence in terms of money—672 kWh means 672 units per hour means 672 × 4.0 INR per hour = 2688 INR per hour = 64,512 INR per day =1,935,360 INR per month = 23.224 million INR per year (USD 357,292.30).

Hence the payback period of the project will be = 42.35 million INR/23.22 million INR = 22 Months Approx.

After this payback period we are getting 672 kWh or 672 Units per hours as totally free which will save 1.935 million INR (USD 297,692.30) per month or 23.224 million INR (USD 357,292.30) per year.

6.2. In Terms of Power Consumption in Cement Production

Total power consumption per day in a 2.0 MTPA cement plant is = 5556 × 95 units = 527,820 units/day.

While we are generating 672 × 24 units = 16,128 units/day.

Hence actual consumption will be= 527,820 − 16,128 = 511,692 which is equal to 92 units per ton of cement.

Hence total 03 units per ton of cement production will be reduced. Hence total reduction per year will be = 5556 ton × 30 days × 12 months × 03 units = 600,480 *i.e.* 6.0 million units per year.

6.3. In Terms of Environment

Total generated output power = 672 kWh = 672 units/hr.

Hence total units generated per year = 672 × 24 × 30 × 12 = 5806080 units = 5.8 million units per year.

This generated energy is absolutely green energy and pollution free in nature.

Hence total reduction in green house gases will be

- 5,806,080 × 0.91 Kg of CO_2= 5,283,532.8 Kg CO_2.
- 5,806,080 × 6.94/1000 Kg of SO_2 = 40,294.1952 Kg of SO_2.

- 5,806,080 × 4.22/1000 Kg of NO = 24,501.65 Kg NO.

Hence, we are saving emission of 5283.532 ton of CO_2 per year, 40.294 ton of SO_2 per year and 24.501 ton of NO per year from a single cement plant of 2.0 MTPA capacities, using 3P.H. technology.

Reduction of emission in such amount will definitely result and effect up to a great extant in reduction of green house effect by reducing temperature and hence global warming to. This will help our society in a positive direction. Reduction in such amount of emission of green house gases is very important as per I.P.C.C study and warning.

6.4. In Terms of Raw Coal Availability

$$\begin{aligned} \text{Total generated output power} &= 5{,}806{,}080 \text{ units per year.?} \\ &= 5{,}806{,}080 \times 0.8 \text{ Kg of coal per unit} \\ &= 4{,}644{,}864 \text{ Kg of coal per year} \\ &= 4644.86 \text{ ton of coal per year} \end{aligned}$$

Hence we are saving 4644.86 ton of coal per year from a single cement plant of 2.0 MTPA capacities by installing 3P.H. technology in plant.

All these benefits are only from a single plant. Applying 3.P.H. technology in whole cement industry will multiply the results up to a significant level.

7. Variations Expected on Results

So far we have discussed till now about the technical data, output and different parameters etc. All these will vary up to some extent on account of the following facts.

7.1. Due to seasonal Variations

Average wind speed varies with season to season. Generally it is recorded that wind speed in the month of May, June, July and August, is higher side while in the months of October, November, December, and January it is on lower side. In remaining period it remains in middle range. Due to these variations of wind speed with season total output power may vary up to certain extant.

7.2. Variations Due to Ducting Size

Calculations for wind power output are based on turbine rotor diameter and on size of ducting used that is on amount of augmentation used. These parameters are dependent on various factors like availability of space, feasibility in fabrication, fabrication cost, maintenance cost , load bearing capacity of preheater tower and finally on designed/desired output. So all the dimensions are site dependent and also depend on a particular preheater tower. Project feasibility and economics are also important to decide all parameters.

7.3. Variation in Emission Calculations

Amount of green house gases depends on type and quality of coal used for power generation and hence amount of emission vary with the type of coal used.

7.4. Variation in Wind Speed Due to Climate Change

In recent years it is observed that due to global climate changes the average annual wind speed is increased, which is an advantageous factor for installing 3P.H. concept in cement plants. This increment is continuously going up and hence encouraging us to install 3P.H. in cement industry.

8. Conclusion

The research paper shows the reduction in emission of green house gases during production of cement in cement industry. Simultaneously, implementation of this technology in cement industry reduces the power cost in cement production and hence reduces coal consumption through which cost saving in monetary terms is also possible. Since raw coal reserves are fixed in the world hence this technology is very useful to save raw coal of cement producing countries. Since availability of good average wind speed in cement plant preheater top reduces the installation of augmented wind turbine, hence the payback period is low which in turns increases the profit of the industry.

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