Waste Technology (WasTech)
Journal homepage: http://ejournal.undip.ac.id/index.php/wastech
An International Journal

Fly Ash Slurry Transportation: Indian Scenario

Md Aquil Ahmad*[a], Zeeshan Ali*[b], Md Emamul Haque*[c]
Department of Mechanical Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia (Central University), New Delhi 110025, INDIA
[a]aquil99@gmail.com; [b]zeeshanjmi71@gmail.com; [c]haque.emam@gmail.com

Abstract – *Fly ash produced in pulverized form are menace to transport due to its powder form. Converting it to slurry form as the physical state change makes it technically viable to move from one place to other convenience to transport. In this paper we envisage the contemporary scenario of transportation of flyash including special focus on trouble related to flyash transportation whether to use in backfilling of mines or open area disposal the transport of these fine particle ash is an issue. Further suggestions and improvement for working of fly ash*
Key words – *fly ash; slurry; Indian scenario*

Doi: http://dx.doi.org/10.12777/wastech.2.1.2014.1-7
Citation: Ahmad, M.A., Ali, Z., and Haque, M.E. 2014. Fly Ash Slurry Transportation: Indian Scenario. **Waste Technology 2(1):1-7 Doi**: http://dx.doi.org/10.12777/wastech.2.1.2014.1-7

Introduction

Fly ash is one of the residues generated in the combustion of coal.It is generally captured from the chimneys of furnace of coal-fired plants.Formerly,fly ash was generally released into the atmosphere but pollution control equipment mandated in recent decades now requires that it be captured prior to release.Fly ash generally contains silicon dioxide(SiO_2) (both amorphous and crystalline) and calcium oxide(CaO).

The thermal power plant ash generation has increased from about 68.88 million tonnes during 1996-97 to 163.56 million tonnes in 2012-13 and is expected to increase more on account of increased power generation.

Many kinds of environmental problems are known to be associated with the deposited fly ash such as land degradation and degradation of quality of air and water. The problem of storing the fly ash creates considerable demand for land. Also, during the periods of heavy precipitation overflow from the fly ash ponds can contaminate the surrounding water bodies and agricultural lands.

Fly ash has been used in concrete since 1930s due to durability and structural benefits. Since fly ash concrete has low permeability, it is less sensitive to chloride, sulfate and carbonation attacks. Also, incorporating fly ash in concrete significantly reduces cracking due to thermal stresses, because the heat of hydration is lowered. Blended cements used in concrete currently incorporate 15_30% fly ash. This can be increased to 50-60% for some particular applications, by using high volume fly ash (HVFA) concrete.

Description

Fly ash is fine glass powder, whose particles are generally spherical in shape and its size ranges from 0.5 to 100 μm. The principal constituents of ash are **silica**, **alumina** and **iron oxide.** Depending upon the type of coal used, fly ash is classified into two types as class F and class C. Anthracite and bituminous coal produces fly ash classified as class F whereas class C fly ash is produced by burning lignite or sub-bituminous coal(fly ash from thermal power plants-waste management and overview, ManasRanjanSenapati). Indian coal is of low grade and contains high ash content up to 40% in comparison to imported coals which have ash content of the order of 10-15%.

Table 1. Thermal power generation, coal consumption and ash generation in India.*(Source:Fly ash from thermal power plants – waste management and overview, ManasRanjanSenapati)*

Year	Thermal power generation (MW)	Coal consumption (Million tons)	Ash generation (Million tons)
1995	54,000	200	75
2000	70,000	250	90
2010	98,000	300	110
2020 (expected)	137,000	350	140

Composition of fly ash

Coal fly ash elemental analysis on a dry basis shows Si(29.39%), Al(13.40%), Ti(1.01%), Fe(1.58%), Ca(1.71%), Mg(0.77%), and O_2(50.43%) to be the major elements present (Effects of pulverized coal fly ash addition as a wet end filler in paper making, Akhouri Sanjay Kumar Sinha). In Table 2, normal ranges of chemical composition of Indian fly ash are given:

Table 2. Normal range of chemical composition of Indian fly ash produced from different coal types (expressed as percent by weight). *(Source: www.coalnic.in)*

S. No.	Component	Bituminous	Sub bituminous	Lignite
1.	SiO_2	20-60	40-60	15-45
2.	Al_2O_3	5-35	20-30	10-25
3.	Fe_2O_3	10-40	4-10	4-15
4.	CaO	1-12	5-30	15-40
5.	MgO	0-5	1-6	3-10
6.	SO_3	0-4	0-2	0-10
7.	Na_2O	0-4	0-2	0-6
8.	K_2O	0-3	0-4	0-4
9.	LOI	0-15	0-3	0-5

Properties of fly ash

In Figure 1, Granules and Cenospheres of fly ash are shown. A 'Cenospheres' is a lightweight, inert, hollow sphere filled with inert air or gas, typically produced as by product of coal combustion at thermal power plants. Due to the hollow structure 'Cenospheres' have low density and now 'Cenospheres' used as fillers in cement to produce low density concrete.

The color of fly ash can vary from tan to gray to black, depending on the amount of unburned carbon in the ash. The lighter the color of fly ash, chances of the lower carbon content (Carlson & Adriano, 1993).

Table 3. Properties of fly ash*(source:Effects of pulverized coal fly-ash addition as a wet-end filler in paper making, Akhouri Sanjay Kumar Sinha)*

Fly ash properties	**Average value**
Mean particle size, µm	30
Bulk density, Kg/m^3	0.897
Brightness, % ISO	28.5
pH	8.5
Specific surface area, m^2/g	1.45
Refractive index	1.7
Color	Brown

Fly ash is siliceous or aluminous with an alkaline nature and has an average specific surface area of 1.45m^2/g.

Porosity and Bulk density of fly ash is an important parameter, which determines the strength,compressibility and drainage characteristics of the embankment. Fly ash can be compacted easily at low or below the Optimum Moisture Content (OMC) and a minimum of about 90% relative compaction can be achieved in the field (Gray & Lin, 1972).

Shear strength tests conducted on freshly compacted fly ash samples show that fly ash derives most of its shear strength from internal friction, although some apparent cohesion has been observed in certain bituminous (Pozzolanic) fly ashes (Di Gioia*etal*., 1972). The shear strength of fly ash is affected by the density and moisture content of the test sample,with maximum shear strength exhibited at the optimum moisture content (Lamb *et al*., 1974).

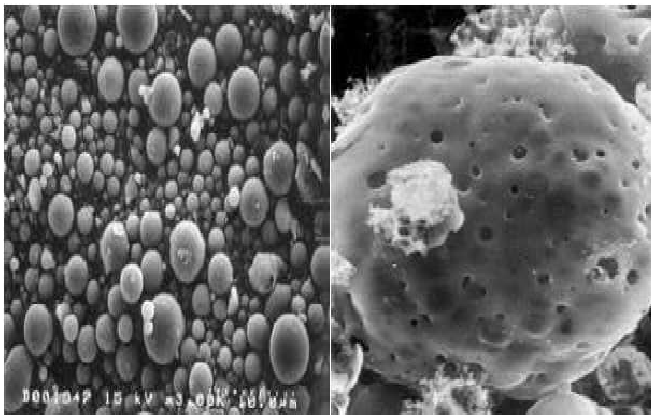

Figure 1: Granules and hollow Cenospheres of fly ash

Management

Since the production of fly-ash has increased from 68.88 million ton in 1996-97 to 13.56 million ton in 2012-13 and is expected to be 140 million ton in 2020 (CEA annual report, 2012-13), it is required to increase its consumption. India achieved highest utilization of 62.60% in the year 2009-10 and 61.37% in the year 2012-13 (Central Electricity Authority 2011-12). Significant efforts have been made by Government of India to increase its utilization in various sectors.

Table 4. Progressive fly Ash generation and its utilization during the period from 1996-97 to 2012-13.*(Source: Central Electricity Authority, annual report on fly-ash generation-utilization 2012-2013)*

S. No	Year	Fly Ash Generation (Million-ton)	Fly Ash Utilization (Million-ton)	Fly Ash Utilization in Percentage (%)
1.	1996-97	68.88	6.64	9.63
2.	1997-98	78.06	8.43	10.80
3.	1998-99	78.99	9.22	11.68
4.	1999-2000	74.03	8.91	12.03
5.	2000-01	86.29	13.54	15.70
6.	2001-02	82.81	15.57	18.80

S. No	Year	Fly Ash Generation (Million-ton)	Fly Ash Utilization (Million-ton)	Fly Ash Utilization in Percentage (%)
7.	2002-03	91.65	20.79	22.68
8	2003-04	96.28	28.29	29.39
9.	2004-05	98.57	37.49	38.04
10.	2005-06	98.97	45.22	45.69
11.	2006-07	108.15	55.01	50.86
12.	2007-08	116.94	61.98	53.00
13.	2008-09	116.69	66.64	57.11
14.	2009-10	123.54	77.33	62.60
15.	2010-11	131.09	73.13	55.79
16.	2011-12	145.41	85.05	58.48
17.	2012-13	163.56	100.37	61.37

Table 5. Fly-ash utilization in India during the year 2011-12 and 2012-2013. *(Source :Central Electricity Authority ,Annual Report on fly-ash generation and utilization 2011-12 and 2012-13)*

S.No	Mode of utilization	Quantity of Fly ash used in the mode of utilization			
		2011-12		**2012-13**	
		Million -ton	***Percentage***	***Million -ton***	***Percentage***
1.	Cement	38.08	44.74	41.33	41.18
2.	Reclamation of low-lying areas	14.21	16.71	11.83	11.78
3.	Roads and Embankments	5.54	6.51	6.02	6.00
4.	Concrete	0.63	0.74	1.03	1.03
5.	Ash Dyke Raising	5.86	6.89	10.93	10.89
6.	Mine filling	7.74	9.10	10.34	10.30
7.	Bricks and Tiles	5.83	6.86	9.98	9.94
8.	Agriculture	0.88	1.03	2.50	2.49
9.	Others	6.28	7.38	6.41	6.39
	Total	**85.05**	**100**	**100.37**	**100**

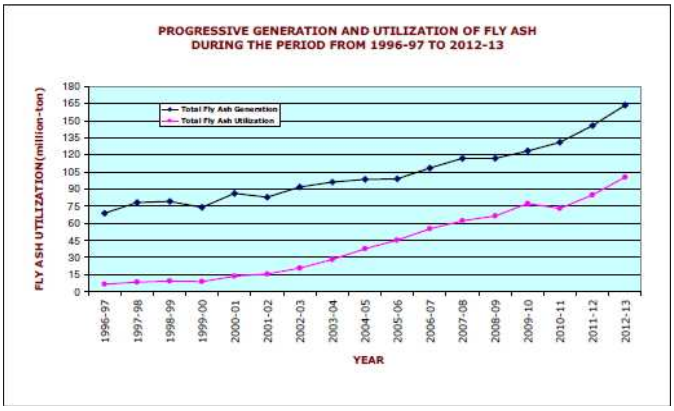

Figure 2: A graph showing progressive fly ash generation and its utilization for the period from 1996-97 to 2012-13.*(Source :Central Electricity Authority, Annual Report on fly-ash generation and utilization 2011-12 and 2012-13)*

Disposal and management of fly ash is a major problem in coal-fired thermal power plants. Fly ash emissions from a variety of coal combustion units show a wide range of composition. All elements below atomic number 92 are present in coal ash. Fly ash can be disposed-off in a dry or wet state. Studies show that wet disposal of this waste does not protect the environment from migration of metal into the soil. Heavy metals cannot be degraded biologically into harmless products like other organic waste. During the last 32 years, extensive research has been carried out to utilize the fly ash in various sectors, as this is not considered as a hazardous waste according to the hazardous waste management and handling ruleof 1989.

Utilization of fly ash in different sectors has been listed in Table 3.2. Cement industries contributes to the maximum use followed by the use in reclamation of low-lying areas and others.

Utilization of fly ash in cement industry

Fly ash can be used in Portland cement concrete to enhance the performance of concrete. As Portland cement contains calcium oxide(CaO), some of the free lime is released during hydration. About 20 percent of free lime is released during hydration of cement. Fly ash reacts with this released lime and produces binder that strengthen the concrete mass. When fly ash is used as a cementitious material, the temperature rise and heat liberated becomes low, thus reducing thermal stresses which minimizes micro-cracking. Also, the unreacted fly ash act as micro aggregates and fills up the matrix to render packing effect that improves many of the properties of concrete and also results in increased strength.

Some of the other benefits are:

- improves workability of concrete
- pore refinement and grain refinement due to reaction between fly ash and liberated lime improves impermeability

- increased resistance to alkali-silica reactivity and sulfate attack
- reduced requirement of cement for the same strength thus reducing cost of concrete
- controls source of pollution

The utilization of fly ash in manufacturing of cement is highly value added use. A graph showing progressive utilization of fly ash by Cement Industry for the period from 1998-99 to 2012-13 is given in the following figure 3.

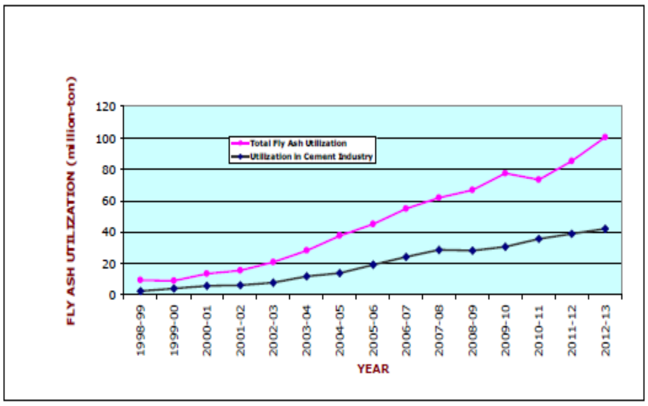

Figure 3: Progressive utilization of fly ash in cement manufacturing and concrete during the period 1998-99 to 2012-13*(Source: Central Electricity Authority, annual report, 2012-13).*

Utilization of fly ash in making roads, pavements and embankments

Fly ash can be used for the construction of roads and embankments. It is used for stabilizing roads due to its high content of calcium and silicate oxides which gives

Utilization of fly ash in brick making

Fly ash bricks are made with/without frog. These bricks are uniform in shape and size, therefore, require less mortar. They are environment friendly as they use fly ash which is a by-product. They are less energy intensive compared to clay bricks and saves agricultural land as they can be manufactured at construction site also. Bureau of Indian Standards have issued code IS: 12894-2002 for ash bricks (NTPC). Unglazed tiles for use on footpaths can also be made from it. Awareness among the people is required and the Government has to provide special incentives for this purpose.

NTPC has manufactured more than 54 crores ash bricks in its various thermal power stations and utilized in construction activities(NTPC). Fly ash bricks are also being used in NTPC's power plant construction works at Rihand, Unchahar and Dadri (Uttar Pradesh), Talcher-Kaniha in Odisha and Ramagundam (Andhra Pradesh).

pozzolanic properties and thus high compression strength (Lahtinen 2001, Mulder 1996). It saves top soil which otherwise is conventionally used and also avoids creation of low-lying areas (by excavation of soil to be used for construction of embankment). Other properties of fly ash like high shear strength, high permeability, grain size distribution, ease of compaction and faster rate of consolidation makes it suitable to be used as a constituent material in making roads and pavements.

Embankment fill is typically an earthen material to use to create a strong stable base. Embankment fills are usually constructed by compacting earthen materials. Fills can be constructed as structural fills where the fly ash is placed in thin lifts and compacted. Structural fly ashfills are relatively incompressible and are suitable for support of buildings and other structures. Non-structural fly ash fills can be used for the development of parks, parking lots, playgrounds and other similar lightly loaded facilities. The permeability of a fly ash fill material is the most important property that affects the embankment construction and its performance quality. The permeability of well compacted fly ash has been found to range from 10-4 to 10-6 cm/sec (Di Gioia et al., 1979). Some of the other engineering properties when fly ash is used as fill material are its moisture-density relationship, particle size distribution and shear strength, are also significant. Fly ash has proved to be versatile material with many possible applications in highway embankment filling.

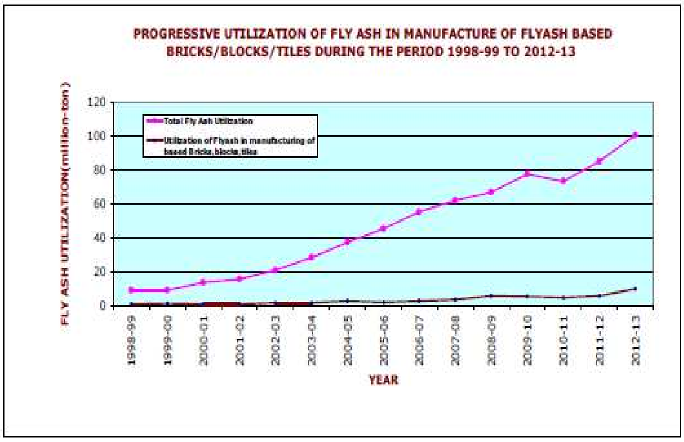

Figure 4: Progressive utilization of fly ash in manufacture of bricks/tiles/blocks during the period 1998-99 to 2012-13.*(Source: Central Electricity Authority, annual report, 2012-13)*

Utilization of fly ash in agriculture

Agriculture and waste land management have emerged as prime bulk utilization areas for fly ash in the country. The same fly ash that causes harm when it settles on leaves can prove beneficial when applied scientifically to agricultural fields as it enriches the produce with Ca and Fe which are good for human being from nutritional point of view. Detailed investigation on these aspects were undertaken at National Institute of Nutrition (NIN), Hyderabad under supervision of Indian Council of Medical Research (ICMR) and Institute of Physics (IoP), Bhubaneswar, Department of Atomic Energy.

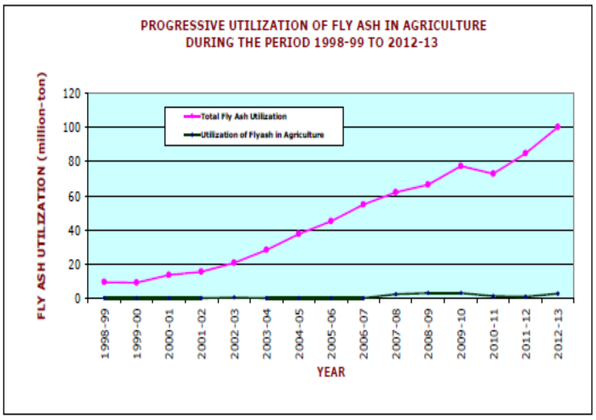

Figure 5: Progressive utilization of fly ash in agriculture during the period 1998-99 to 2012-13*(Source: Central Electricity Authority annual report, 2012-13)*

Fly ash can be used as soil modifier and enhance its moisture retaining capacity and fertility. It improves the plant's water and nutrient uptake, helps in the development of roots and soil binding, stores carbohydrates and oils for use when needed, protects the plant from soil-borne diseases and detoxifies contaminated soils. It also provides micro nutrients like Fe, Zn, Cu, Mo, Bi, Mnetc and macro nutrients like K, P, Ca, Mg, S etc. Crops grown on fly ash amended soil are safe for human consumption and groundwater quality is also not affected.

Table 6. Effect of fly ash on yield of crops
(Source: Fly Ash India 2005, New Delhi)

Name of crop	Percentage increase
Groundnut	40.2
Sunflower	25
Safflower	15.2
Maize	12
Paddy	10.5-18

Table 7. Total and available micronutrients in fly ash
(source: Fly Ash India 2005, New Delhi)

Parameters	Total	Available (ppm)
Cu	40-80	0.5-1.6
Zn	50-150	0.4-1.8
Mn	500-750	0.9-1.5
Fe	3.3-6.4	10-15
B	17-38	0.5-0.8
Mo	2.2-6.7	0.1-0.6

Utilization of fly ash in paper making

Fillers which are finest particles of fly ash having average particle size of 19 micrometers mixed with kaolin clay are used in papermaking. These fillers are inert material and they adversely affect most of the mechanical strength properties by interfering directly with inter-fiber bonding. Addition of fly ash causes lesser decrease in mechanical strength properties because of its larger particle size and irregular shape compared with kaolin clay. The constituents of both fly ash and kaolin clay are silica (SiO_2) and alumina (Al_2O_3). However, fly ash also contains other oxides such as titanium dioxide, magnesium dioxide, calcium oxide and iron oxide, which provides higher opacity and lower brightness in paper.

Transportation

The deposit of large amount of fly ash and bottom ash discharged from coal-fired power stations is an earnest task. The amount of fly ash generated is larger than bottom ash. Due to high quantity of generation, it remains in abundance despite numerous utilizations. Thus, it is expected that large amount of fly ash must be transported from power station to deposit site.

Fly ash slurry with over 60% solids by weight, with typical medium to high viscosity forms a natural slope on the disposal area without the need of mechanical spreading and with minimal release of water. This technology also referred to as 'High Concentration Slurry Disposal' or 'dry stacking'. The advantages of the technique include reduced airborne dust, material handling on continuous basis, easily automation process and so on.

Preparation of fly ash slurry

The composition of water and solid plays an important role in the transportation of formed slurry. Depending upon the composition, slurry may be classified as:

- **Low Concentration Slurry Disposal (LCSD) or lean slurry disposal system (10-30 % by weight)**
  Due to high water content, slurry can be pumped to long distances but important hydroxides areleached out which renders the deposited materials loose and ash stone is rarely produced.
- **Medium Concentration Slurry Disposal (MCSD) or moistened system (40-50 % by weight)**
  In this case, the amount of water used is sufficient for slaking free CaO and activating other components. It is convenient to further moisten the slurry in order to ensurehigh density, high strength and low permeability.
- **High Concentration Slurry Disposal (HCSD) or dense slurry system (60-70 % by weight)**
  High concentration slurry is formed by intensive mixing, which is then pumped to disposal sites through pipelines where it gets converted into ash stone within few days.

➢ **Mixing Process**

In order to slake free calcium oxide and to activate other compounds, fly ash and water requires intensive mixing which is performed on mixers. The mixers are designed for intermittent or continuous operations in which intensive agitation is achieved by circulation slurry pumps. The homogeneous suspension thus produced has its density in the range of 1.25 to 1.70g/cm^3. The thick fluid is grey in color and its temperature is around 40^{o}C.

Dense slurry mixer system

One of the types of mixers employed in the mixing of ash with water is the Circumix® type continuous flow mixer. It has two mixing stages, the pre-mixer head, and a mixer tank for final mixing. The mixer is specially designed for high and low capacity ash handling applications in power plants.

A dosing device, at the top, feeds the dry ash into the pre-mixer by gravity. Water enters into the cylindrical shaped pre-mixer tangentially and is dosed proportionally to the ash flow. Slurry pumps are incorporated for circulation of dense slurry from final mixer tank to pre-mixer tank for better mixing and homogenizing. The final homogeneous ash slurry leaves the mixer from the tank circulation loops through a slurry discharge valve. The slurry level is generally controlled by the material feed.

The size of the mixer is designed so as to ensure a proper residence time of the slurry mixture, considering the chemically reactive CaO(free) and $CaSO_4$ components of the fly ash.

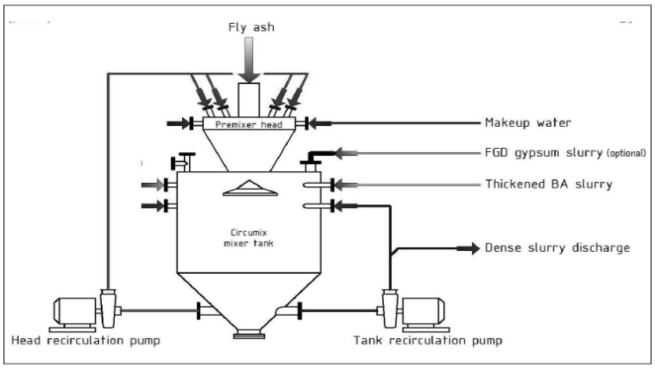

Figure 6: Connection diagram of Circumix® mixing loop and distant transport line*(Source:Circumix® Dense Slurry Technology)*

Slurry pipeline Flow

The pressure drop of a slurry flow in a pipeline varies with flow velocity. However, unlike a pure liquid flow, it is not monotonic (Vanoni 1975; Govier and Aziz 1977), as shown in figure7:

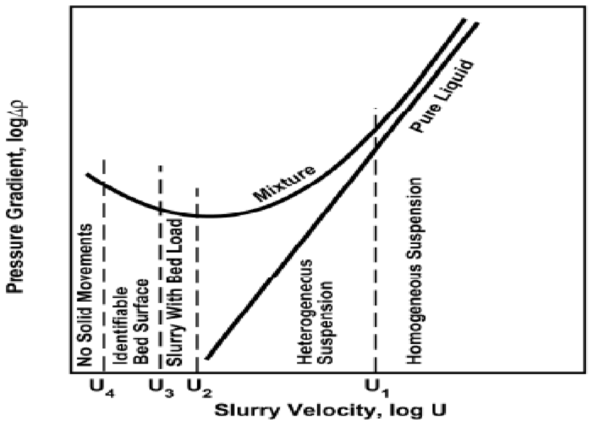

Figure 7: Pressure Drop Variation WithVelocity.*Source (Pipeline Cross-Site Transfer Assessment for Tank 241-SY-101 Waste; Y. Onishi, B.E.Wells, S.A. Hartley, S.K. Cooley)*

At sufficiently high velocity, all solids are suspended and their distributions are vertically homogeneous. Homogeneity in flow means the various properties of suspensions (like solid concentration, density, viscosity) do not change across the pipe. Homogeneous flow of suspension is possible if the following conditions are satisfied:

- The solid particles are finely dispersed and light.
- The slurry flow rate is sufficiently high.
- The solid concentration is high.

For homogeneous flow, it is essential to have the terminal settling velocity of the particles as small as possible.

As the flow velocity decreases below a certain point, U_1 (figure 7) (Govier and Aziz 1977), all of the solids are still suspended but their distribution becomes vertically heterogeneous. As the velocity further decreases to the critical velocity U_2, some solids start to move (e.g., sliding, hopping, jumping) along the pipe bottom as a "bed load". At this point, the pressure drop usually becomes the minimum. As the velocity decreases further, fewer solids move as the suspended load, and more solids are transported as the bed load. At further reduced velocity, U_3, the bed load starts to generate the bed form. The bed form further increases the apparent pipe fraction factor, resulting in increased pressure drop. Finally at further reduced velocity U_4, all solids stop moving (Wasp Slurry Pipeline Transport Model).

There is a unique velocity corresponding to minimum head loss in the pipeline, below which the settling of solids will occur, but above which, the flow is homogeneous. This velocity is termed the critical velocity (Kokpmar and Gogus. 2001). At critical velocity U_2, the slurry operation is optimized and requires minimum pump pressure. However, once some solids start to move as bed load, more pressure is required to move them. The danger of plugging the pipeline arises if the pump does not have enough extra pressure to overcome this added pressure drop requirement or if the pipeline strength cannotaccommodate this additional pressure requirement. Thus, to avoid potential pipeline plugging, waste transfer through the pipeline must be operated above the critical velocity, U_2.

Above mentioned flow behavior would be strictly valid as long as the particles are equal in size. However in applications such as stowing and filling the particle size in the solids transported varies over a wide range. Hence, at any given mixture velocity the smallest particles may be homogeneously distributed across the pipe cross-section, whereas, concentration gradients would be prominent for the larger particles. Also the largest sized particles would tend to settle first while the other fractions are still under suspension. Thus, for given mixture if all the particles are in suspension then the concentration profile would be uniform for smallest size from, whereas it tends to become increasingly, non-uniform as the size of the particles increases. This would make the suspension flow near the bottom of the pipe increasingly coarser as compared to that flow at the top of the pipe. As the mixture velocity is reduced all the particles belonging to larger size fractions would be traveling in the bottom half the pipe and they tend to settle first. Thus, for multisided particulate suspensions there will be a combination of homogenous and heterogeneous flow. Further, the transition velocities (U_1 to U_4) are not clearly defined and the different flow regions are not clearly distinguishable (Seshadri, 1997).

Critical Velocity

The slurry pipe flow velocity must be above the critical velocity based on the following conditions:

- It must be above U_2 (figure 7), to have all the solids suspended
- It must be turbulent (for a pipe flow, Reynolds number of above 2100 ~ 2400)
- It must overcome the yield strength of the slurry, if any.

a) By Wasp Slurry Pipeline Transport Model

Wasp proposed the following model for the calculation of critical velocity, considering the solid concentrations and the mean particle size for more widely varied particle sizes:

No bed load

$$U_c = 3.116 Cv^{0.186}\left[2gD\left(\frac{PS-PL}{PL}\right)\right]^{\frac{1}{2}}\left(\frac{d}{D}\right)^{\frac{1}{6}} \qquad (4.3)$$

where,
Cv = total volume solid fraction;
D = pipe diameter;
d = particle diameter (weighted mean diameter for mixed sizes);
g = gravitational acceleration;
U_C = critical velocity;
PS and PL = solid and liquid densities, respectively.

b) by Kokpamar and Gogus (2001)

The terminal settling velocity of the solid particles is taken into consideration in the proposed model of Kokpmar and Gogus (2001), for the determination of critical velocity of slurry flow. The approach differs from other formulations on account of the consideration of the settling velocity of particles.

The Kokpmar and Gogus (2001), model is given by:

$$\frac{Uc}{gD} = 0.055\left(\frac{d}{D}\right)^{-0.6} Cv^{0.27}(S-1)^{0.07}\left[\frac{Pf\ Wm\ Ds}{uf}\right]^{0.30} \qquad (4.4)$$

where,
Uc = mean critical flow velocity of solid—liquid mixture (m/s);
Cv = concentration of solid materials by volume;
D = pipe diameter(m);
Ds = mean particle diameter (m);
S = specific gravity;
Pf = density of fluid(kg/m^3);
Wm = particle settling velocity in mixture flow (m/s);
uf = dynamic viscosity of fluid (kg/m-s);
g = gravitational acceleration(m/s^2)

Conclusion

The fly ash generated from the combustion of coal can be utilized in numerous sectors. A major portion of fly ash is consumed in cement industry. It can be successfully used in agriculture and construction of roads and embankments. High cost involved in the dumping of fly ash makes it more favorable to be used. However, there is a requirement of fly ash transportation as the rate of its production is much higher than itsutilization. Fly ash slurries are prepared and transported through pipes to low-lying areas where it is deposited. The guidelines of all thermal power stations regarding fly ash slurry disposal should be in such a way that its adverse effect on environment is minimized. The future poses challenges to the scientists, technologists, engineers towards sound management of fly ash disposal & deposition technologies.

References

[1] Haque, Emamul M., "Indian fly-ash: production and consumption scenario", International Journal of Waste Resources (IJWR), Volume 3(1), Issue March,2013.
[2] Arvind Kumar Rai, Biswajit Paul, Gurdeep Singh," A Study on Backfill Properties and Use of Fly Ash for Highway Embankments", Volume 1, Issue 2, October,2010.
[3] ManasRanjanSenapati, "Fly ash from thermal power plants-waste management and overview", current Science, Vol. 100, No. 12, 25 June 2011, Pages 1791-1793.
[4] Akhouri Sanjay Kumar Sinha, Manohar Singh, Surendra Pal Singh, "Study of use of Beneficiated Pulverized Coal Fly-ash as filler and rice straw fibers in manufacturing of paper".
[5] Asokan, P., Saxena, M., Asokan, A., et al., Waste Management & Research 22(4):265(2004)
[6] Kumar V., Singh G., (2005) Flyash: A material for another Green Revolution, Fly ash Utilization Programme (FAUP) 2005, TIFAC, DST, New Delhi.
[7] Rao, B.K. and Kumar Vimal, (1996), Fly ash in high strength Concrete, Recent Advances in Civil Engineering, National Seminar, September 28, pp.115-12.
[8] Verma, S.,(1997), 'Performance Evaluation of High strength Fly ash concrete paving mixes', M.E.
[9] Akhouri Sanjay Kumar Sinha, "Effects of pulverized coal fly-ash addition as wet-end filler in paper making", September, 2008.
[10] Haque, Emamul M., "Indian coal: production and ways to increase coal supplies", International Journal of Scientific and Research Publication (IJSRP) Volume 3, Issue 2, February 2013.
[11] Kokpmar, M., Gogus, M. (2001) "Critical Flow Velocity in Slurry Transporting Horizontal Pipelines." Journal of Hydraulic Engineering, September 2001.
[12] Carlson, C.L. and Adriano, D.C. (1993), "Environmental Impacts of Coal Combustion Residues", J. of Environ. Quality, 22: 227-247.
[13] Di Gioia, A.M. & Taylor, L.R. (1979), Fly ash structural fill, Electric Power Research Institute, Report No. EA-1281, Palo Alto , California, USA.
[14] Parisara, ENVIS Newsletter," Department of Forests, Ecology and Environment, Government of Karnataka", January, 2007, Volume 2, No. 6.
[15] Sunil Chandel, S.N. Singh, V. Sheshadri,"Transportation of High Concentration Coal Ash Slurries through Pipelines", International Archive Of Applied Sciences and Technology, Vol. 1[1], June 2010, 1-9.
[16] Circumix Dense Slurry Technology, Competent solution for handling combustion residues for coal fired power plants.
[17] Y.Onishi, B.E. Wells, S.A. Hartley, S.K.Cooley, "Pipeline Cross Site Transfer Assessment for tank 241-SY-101", Report prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830, Pacific Northwest National Laboratory, Richland, WA.
[18] Govier G.W. and K.Aziz .1997, "The flow of complex mixtures in pipes", Robert .E. Krieger Publishing Company, Inc., Malabar, Florida.
[19] HiromotoUsui, Lei Li and Hiroshi Suzuki, "Rheology and pipeline transportation of dense fly ash-water slurry", Korea-Australia Rheology Journal, Vol. 13, No. 1, March 2001 pp. 47-54.
[20] Ministry of Coal Government of India, Annual Report 2011.
[21] Central Electricity Authority India 2012-13, Annual Report on Fly-ash utilization.
[22] India Energy Book 2012, (World Energy Council, Indian Chamber Committee)
[23] www.iflyash.com, www.coalnic.in, www.ntpc.co.in