Some Technical Idea Evolutions Concerned with Electrostatic Precipitators in China

WANG Liqian[1], FU Bohe[2]
(1 The Chinese Society of Electrostatic Precipitation Chindias Enviro & Energy Technologies, Ltd., Nanjing 210018, PR China
E-mail: Wanglq4602@163.com
2 Shandong Shengjie Energy Environment Engineering Co., Ltd., Jinan 250014, PR China
E-mial: bohefu66@163.com)

Abstract: Electrostatic precipitator (ESP) was applied in China more than fifty years. There are many technical idea changes along with time or idea corrections from misunderstandings in this long run. A historical review of them will not only be interesting but also can draw some inspirations from them.

It is not possible to look back all the technical events. Only those have discussed thoroughly among Chinese ESP workers, such as: gas velocity in ESP, height of collecting electrodes, dust cleaning methods, selection of T/R and control modes, etc. are briefly described in this paper.

Two special topics, ESP for circulating fluid bed boiler and Orimulsion® combustion are also referred with. They are different kind of problems, but have drawn divergences between Chinese engineers. So, as an assortment, described here.

Keywords: ESP, gas velocity, field hight, rapping, energization control, T/R, CFB boiler, Orimulsion

1 GAS VELOCITY IN ESP, V

There have two ESP design golden rules in 1950's. The one is the gas velocity in electric fields should not exceed 1m/sec. The other is the height of colleting electrode should not higher than 4.5 m.

The young ESP designers in China carefully obeyed these rules. But in viewing of the high cost of ESP, especially for a poor country like young new China, we always want to break the forbidden area after we have accumulated some experiences. Hence a lot of small and pilot ESP was tested in which **V** lied in the range of 1.5 m/sec–2.0 m/sec. In1957 one small pilot ESP [1] for collecting pyrite iron ore, velocity of 2 m/sec was selected, gave a collection efficiency of 98% or slight more which was satisfying at that time. In spite of this was the merely example, our mind was opened to accept **V** more than 1 m/sec.

But in industry scale, we never harvested successes above 1.5 m/sec. In a long run of about twenty years, 1.0–1.2 were mostly selected for industrial ESP.

Entered into 1980's, China imported many fly ashes ESPs from western countries. Again, 98% to 99% efficiencies were designed which corresponding to about 200 mg/Nm^3 –400 mg/Nm^3 emissions. **V** of 1.2 m/sec to 1.4 m/sec was selected by the western ESP companies. We rejoiced that we have foreseen the "tendency" of increasing velocity of ESP.

But, soon afterwards we found, no matter what companies the ESP was imported from, high velocity was very often the main factor conducting failure in accordance with the emission the supplier guaranteed. Especially some top rapping ESPs, of which the design velocity was 1.4 m/sec. Their actual outlet dust concentration greatly went beyond of guaranteed values.

When China adopted the emission standard of 50 mg/Nm^3 since 2004 (It comes later than developed countries several decades) and the power units became 300MW, 600 MW and 1000 MW, Chinese engineering became prudent to using velocity faster than 1 m/sec. They again fund V is the detrimental parameter in high performance ESP.

So, after almost of fifty years, thing go back to the original point. One meter per second again becomes a limit value. Of course, velocity is not the only factor dominating the ESP efficiency, and we can get the same efficiency by using different velocities, yet its importance no one can deny.

We are conscious of not that the velocity itself, but that more in essence, Reynolds number, is playing role. So, fast velocity / small ESP and low velocity/ big ESP, or in other words, a certain degree of turbulence is dominating for some efficiency. The multiple of velocity and hydraulic diameter of the ESP cross sectional area will be a critical parameter.

We remember that the so called FPA, the Fine Particulates Absorber, of which the idea was proposed by Feldman et al [2]. Its basic principle is to develop a laminar flow ESP. Since it is not possible to reduce gas velocity by a big margin, another way is reducing the gas channel width, which in FPA is only about 5 centimeter. So, low Reynolds number of less than 10000 was achieved. FPA can be designed to reach, as it principally said, any high efficiency except 100%, by pure hydraulic calculation because for laminar flow the efficiency can be mathematically predicated. Regret is that FPA is too expensive and pure laminar flow perhaps can never be gotten in big industrial equipments.

Once, about in the beginning of 1980's, Professor Senich Masuda was taking lecture in Wuhan. Introducing about his Boxing Pre-charger, professor said field strength of 10 kV/cm in it was not difficult. There were not less than six to seven kinds of ESP pre-charger in 1970's. I have doubt why, for the same gas and dusts, 10 kV/cm can be sustained in different pre-chargers while only 2 kV/cm–3 kV/cm in common ESP. The answer of Professor was: "Probably it is because of the different velocities between pre-charger and common ESP". This answer had made me puzzling at first. Ten times higher velocity (10 m/sec in pre-charger) gives three to five times higher field strength?

From the principle of electric hydraulic dynamics (EHD), higher gas velocity really gives higher field strength. But in real ESP, we cannot select 10 m/sec grade velocity because of strong reentrainment and other considerations.

So we have to move back to low velocity. That means 1 m/sec more or less is really a critical value. It corresponds to Reynolds number of about some 10^5, as channel width (spacing) to be the characteristic length.

Recently, in the design of high performance ESP, say emission ≤30 mg/Nm^3, we noticed the parameter "residence time" T become important, perhaps as important as gas velocity. I analyzed some Chinese fly ash ESPs which gave emission of ≤50 mg/Nm^3, the T value were in the range of 20–25 seconds. For a four 4- meters long fields ESP, it means the gas velocity V is better not exceeds 0.8 m/sec, especially for Chinese difficult coals.

Actually, "residence time" is nothing but the ESP inner volume occupied by one cubic meter per second of gas. In viewing of V should be small enough and T big enough respectively for high performance ESP, I suppose it perhaps better to choose more wide spacing, say 450 mm or more instead of 400 mm. Here we only increase the weight of casing, but not for the weight of DE and CE electrodes so as to obtain longer "residence time".

In another side, too low velocity can conduct hot gas temperature gradation in ESP, also not well for high performance.

2 FIELD HIGHT, H

The second design rule in 1950's was concerned with the field height. i.e. height of CE plate should not be higher than 4.5 m. It was said one of the reasons for setting this rule is the misalignment between DE and CE will not be able to keep in 2 mm limit value if higher CE was selected.

Of course, higher CE plate gives less accuracy of electrodes alignment, hence less working voltage, more time needed for dust sedimentation down to the hopper and more reentrainment.

We followed this rule till 1960's. Only non-ferrous metal, sulfuric acid and cement industries equipped with ESPs in that age of China. Power and iron & steel industries still used cyclones, scrubbers or bag filters, etc. Later, the increasingly big production installations forced us to use big ESP with higher CE plates. I remember we have "bravely" designed a 6.75m height rod curtain CE for an alumina sintering rotary kiln in 1968 [3]. We also built another 7meters high plate ESP for bauxite clinker crushing process at same time. Both were working well. By the way, the 7 m height CE plates maintained misalignment of less than 2 mm with DE by senior bench work fitters.

Two millimeter misalignment limit is rather stringent. Actually, 5 mm discrepancy could be allowed for small industrial ESP.

A cement kiln ESP was designed by Chinese engineer in 1977. Its effective field height was 8.7 m. The designer won special award because of its very good performance [4]. This is the top level in China of 1970's.

Since 1979, the year of open and reform, a lot of big ESPs for cement kiln, iron ore sinter band and utility coal-fired boilers were imported and then designed by ourselves with CE plate height lies between 10 to 15.6 m.

Now, a new "rule" of 15 m-16 m high CE plates actually exists in spite of nobody saying it is the ultimate limit. Compare to 4.5 m limit; which was broken through in about fifteen years, the 15 m-16 m limit already existed about twenty years. For 300 MW coal units or about 2 million m^3/hr gas flow, 15 m high is acceptable. Two parallel ESP for one boiler layout has no difficulty. But for 600 MW or 1000 MW units, which are not uncommon now, 15 m-16 m high CE plates give too big width of ESP installation, much wider than boiler's width. Huge, sometimes non-realized land area occupied by ESPs forced us to use two layers ESP layout design, i.e. one ESP with less than 15 m height CE plates putted upon another less than 15 m height CE plates ESP. Generally these double layers ESPs have many difficulties in dust dislodging, gas distribution, operation and maintenance etc., not welcomed by plant people [5].

If we can overcome the difficulties of 18 m–20 m CE plates, things will be different. Is really a non- broken limit of 15 m–16 m high fields?

In 1983 and 1984, I visited almost all the important ESPs companies in US and Germany. I specially arranged our schedule to visit a German ESP company, because their catalogue said they have 18 m high ESP. But I was disappointed that they replied me they only has it in brochures. 18m high ESP is to be developed later.

The obstacles may be: Difficulty in sedimentation of fine dust, insufficient of rapping acceleration especially for MIGI top rappers, transportation and erection problems, etc. These are not theoretical but practical problems need full scale investigations and experiments. As 8 m is the limit height of vertical filter bag, 15 m limit of ESP CE height constitute two big problems in dust control technologies. How can we break through these limits?

Perhaps we should jump out of classical idea of ESP constructions, such as: long strips of CE plates, vibration cleaning created by mechanical rapping, etc. May be the Moving Electrodes ESP (MEEP) [6] with fixed brushes located in hopper of Hitachi technology gives a way out. A 20 meters height or even higher MEEP is not unrealized, I think.

3 DUST CLEANING FROM COLLECTING ELECTRODES

In early 1950's, China only have top rapping ESP of mechanical rappers and plates impacting type ESP. The bottom tumbling hammer of European type was only imported in late 1960's. Top rapping of MIGI rappers imported more lately. For small ESPs, all of them are enough for dust cleaning from discharge electrodes (DE) and collecting electrodes (DE).

For big ESP of 15m CE, top rapping force seems insufficient for cleaning the dusts sticking at its bottom end. Both MIGI rapper and top mechanical rapper produce less acceleration than tumbling hammer. In spite of top rapping need small acceleration value for rapping down dust layer than side bottom rapping, many Chinese ESP experts consider top MIGI rapper is only safe for CE plates less than 12m height.

A lot of improvements were made by Chinese technicians in order that MIGI rapper can be used for 15 m plates. But for heavy sticky dust, we prefer choosing tumbling hammer.

MIGI rapper installation has springs for protecting porcelain bushing insulator from direct impact. But just these springs damp the rapping force. Another drawback is the rapping bar always standing on the collecting plates hanging beam, this gives long contacting time, which reduce acceleration value markedly.

In one ESP [7] of 600 MW units with CE plates of 15.24 m high, we have canceled the three springs on the top cover of support bushing for increasing rapping force. Moreover, more rigid conjunctions between force transmissions elements were designed. This ESP was basically working well without dust sticking on the plate surface. The original designer of MIGI system does not agree this corrections; he said the springs do not influence the rapping effect because of the high frequency vibration would not be reduced by springs. The low frequency vibration will be reduced by spring but it does not play main role for dust cleaning. However, canceling of springs has not injured insulators and gives satisfying plate cleanness in this special case. Very good quality high alumina content bushing can endure the rapping force without broken.

In view of so many troubles in the Chinese tumbling hammer rapping systems, Chinese engineers were continually investigating the way to avoid these breakdowns. In 1984, a strong opinion was proposed by a Chinese T/R company. It was said that the mechanical rapping system troubles could be entirely eliminated by canceling mechanical rapping. Instead of it, the vibration caused by strong spark over is enough for dust layer peel off from CE plate. And there is no problem to made T/R sets working safely at very high spark rate.

It is no doubt that vibration caused by electrical spark has dust cleaning effect. From one US literature, I have read that an ESP had worked normally for 11 days by spark induced vibration only.

There was another example in China. In 1966, a 15 m^2 (cross sectional area), 3 fields ESP for sulfuric acid production plant in Chengdu [8] suffered big difficulty of dust sticking both on DE and CE. Almost zero current displayed. Increase the hammer weights could not rap down the sticky dusts. Corona current still stands near zero point. So, the ESP must be stopped for manually cleaning. The electrical engineers of this plant and the teachers of Sichuan Institute of Technology designed and made by themselves a so-called "capacitive rapping" installation[3]. It was a big self-made capacitor of several ppf capacitances parallel connected with the ESP. The size of this capacitor was as large as an office table. T/R energized the ESP and capacitor at same time. A saturable reactor was used as main control element. Once the capacitor was full charged, it automatically released most of its charges in a very short moment; created a loud thunder accompanied with explosively gas expansion and vibration in ESP. This method eliminated the fat DE wire and gave bigger corona current. But, for macroscopic evaluate, even such a terrible "spark over"—thunderbolt, its dust cleaning effect was only slightly delayed the manual cleaning time from one week to about fifteen days.

So, the "spark over rapping" can only be an auxiliary provision of the mechanical rapping. Same as it is the acoustic horn, which became popular recently in China, has clean effect but cannot be substitute of the mechanical rapper.

Chinese engineers developed the moving brush ESP for iron sinter strand [9] It is an auxiliary provision for tumbling hammer. Stainless steel brushes were amounted of a horizontal frame. Once the corona markedly reduced, resembling thick dust layer could not be rapping down. Then the brush frame moved down from its standing position above the DE and CE. Only once or twice of power switch off up-down-up moving cycles totally within about one minute, CE was well cleaned. For ESP not bigger than 80 m^2 (cross sectional area), it works safely and efficiently.

We also knew the Hitachi MEEP worked well with bottom brush and rotating CE plates in large ESP. May be the brush can be good substitute for rapper!

4 ENERGIZATION CONTROL MODES

The history of ESP energization control can be approximately divided into three stages, i.e. constant voltage stage, constant current stage and sparkover control stage.

4.1 Constant Voltage Control (CVC)

This control mode appeared in the early days of ESP application. People knew that the higher the voltage, the higher the dust collection efficiency. Hence to keep a high voltage constantly is a very natural control idea. The hardware used for CVC is inductive voltage regulators.

But the shortcoming of CVC was found before long. Problems occurred from the fact that:

- The breakdown voltage of the gas treated is not constant but varies instantaneously with temperature, moisture, gas and dust composition changing, etc. No matter how stable the boiler or furnace works, they never can be constant. A constant working voltage setting, no matter how representative it is, cannot approach closely with the continuously varied breakdown value.
- If the dust content in the gas is increase, the ESP working power should be, no doubt, increase. But in

case of CVC, the working current, hence the working power will be reduced.

The conclusion is, CVC is not a good idea. CVC had been abounded before it's widely spread.

At the time of I knew ESP first, early 1950's, the so-called Step by Step Voltage Control method was used. The idea is: set a voltage at first (constant in this short period), and then periodically test to increase it step by step till the switch drop out. Three times of switch dropping out is the signal for power switch off. The voltage regulator was pure resistive. Although this method implicated the advanced automatic continuously control of follow the track of a small spark ten years later, it was rough enough to injure the control element and corona wire by non-avoidable big sparks or even arc discharge.

Mechanical rectifier was used at that time. Because of its non-continuous energization, fixed rotation speed and fixed brush length, there was no real meaning of automatic control.

It is interested that we have test the half-wave energization by using two mechanical rectifiers connected serially. Now, by using of the silicon diode bridge type T/R, we can have half wave energizations to two bus sections only by one modern T/R.

4.2 Constant Current Control (CCC)

CVC control appeared in later 1960's in China. Silicon diode bridge built-in type T/R already instead the mechanical rectifier. The voltage regulator was saturable reactor with constant current output.

The most valuable feature of CCC is positively self adjusting. When dust content of gas increases, CCC automatically increase, don't like CVC decrease, working voltage, so also increase power and collection efficiency.

One T/R company near Shanghai developed so-called "Constant Current Power Source" (CCPS)[10,11]. It uses L-C converter instead of saturable reactor for producing constant current. It features:

- Output current is always unchanged, independent with load and ESP internal situations, i.e. gives automatically constant current.
- Net current and net voltage are in same phase, i.e. power factor $cos\Phi$=1 at the input end.
- When output end short circuit, net input current equals zero; beneficial for equipment safety.

Because CCPS consumes more iron and copper, has the drawbacks of heavy weight, big volume and expensive price limited its market in China, especially for large installations. Some Chinese ESP technicians did not accept it for several years.

But the "opposition factions" of CCPS finally recognized it value. In many cases, especially that the gas temperature and moisture fluctuated obviously, CCPS always gave better collection efficiencies than common SCR controller. This is due to its constant current characteristics.

When opposite parallel connected SCR as voltage control elements firstly appeared in the late 1960's or early 1970's in China, conjunct with the control of follow the track of a small spark, it was considered as most advanced techniques. Several years passed, the value of CCC was recognized by Chinese experts again.

4.3 Spark (Rate) Control (SRC)

In China, so many control modes have been described in catalogues.

Group one

A. Spark tracking control,
B. Optimum spark rate control,
C. Critical minimum spark control,
D. Maximum average voltage control, etc.

Group two

E. Non-spark control,
F. Constant spark rate control,
G. Spark rate setting control.

All of the above methods concerned with spark or spark rate. All of them need tracking the spark (or tracking avoid of spark as said for so-called Non-spark control).

Three kinds of idea are involved in the above control modes:

1. Increase working voltage as high as possible with certain sparks or spark rate, no matter how small the spark (rate) is;
2. Increase working voltage as high as possible without any big or small spark;
3. Maintain high voltage under the condition of constant spark rate.

Idea 1 is correct. Ideals of 2 and 3 are incorrect.

The four control methods of Group one are based on idea 1. Actually, method A is means, method B, C and D are purposes. As H. J. White said in his classical book, optimum spark rate lies in 50 times–200 times per minute. I think at his time of 1950's to 1960's; the control technique was not so advanced; the spark rate of 50 times–200 times per minute was generally suitable. It means the working voltage close to and jumping slight over the breakdown voltage with relative big fluctuations. Modern computer technologies bring the possibility of detecting very small spark; fast responding to current/voltage small fluctuations and very precision controlling. In this case we suppose the working voltage goes to breakdown value as close as possible at the same time with very few, very small sparks and also very small fluctuations are better. So, control method from optimum spark rate control switch to critical minimum spark control is a process of technical progression. In this case, we also have maximum average voltage.

Control methods based on Ideas 2 and 3, as Group two, E, F, and G, proposed by some Chinese engineers in 1970's and 1980's, were assigning wrong topics, I think. First, the so-called non-spark control, it means control the voltage as high as possible but without any spark generated. This is pure ideal. Practically we can only detect the gas breakdown voltage by spark. No spark means no signal of gas breakdown; how can we approach the limit? If the gas breakdown voltage is constant, we can set the ESP working voltage a little bit lower than it by a first small spark as a limit signal, then comes "Non-spark control" in later operation. But in this case all the control methods become the same thing and need not control at all. So, as I consider, the utmost control is one by which we can follow the gas breakdown voltage with very small sparks. Actually, for a capacitance load as ESP, the "spark" phenomena is a series of current/voltage fluctuation, no matter how small a spark appears, it always have a more smaller "small spark" preceding it. So, for comparison between two controllers, the one can always maintain higher voltage with smaller spark (less fluctuation of current/voltage) will be the winner. It means from detection to control (hardware and software), every link is superior. Pure "non-spark control" is impossible. In stead of it, "non big spark control" is reality. Of course, here "big" is a relative term.

The so-called "constant spark rate control" F, arose in about 1985 in China. Because of its great in propaganda impetus, idea confusion was made in several years. Many T/R controller manufacturing plants and electric power design institutes said chime in with it that it is the most advanced control method of ESP. Actually this control idea neither theoretical bases nor sufficient practical explanations. Suppose an ESP installation suffered a difficulty of dust load surging, generally more power should be input to ESP for increase the collection efficiency. But if you use the constant spark rate control, the controller may oppositely reduce the input power, because in the dust surging period the spark rate will increase. To keep constant spark rate from higher value, reduce power input is non avoidable.

The optimum spark rate is closely linked with how good the T/R is matched with the ESP. The degree of matches changes with gas and dust properties continuously, constant spark rate could not be a good choice.

The method G, Spark rate setting control, is just a mutation of constant spark rate control. How to set? Once set, at what time to adjust it? It cannot suit for the ever changing gas discharge properties. Hence Idea 3 is wrong also.

So, for a modern big ESP, using sensitive spark detection and vivacious control to achieve real time small spark tracking, small spark voltage drop down and fast ramp for voltage recovery without spark re-burning and continuous flash is the best control mode, i.e. old principle, but new advanced controller.

5 SELECTION OF T/R

5.1 Sizing of T/R

Precisely select T/R size may be as difficult as the selection of migration velocity. Experience again play important role. I have experienced an example in Alumina plant. Two identical three fields ESPs of same type and same size were equipped for two rotary kilns of same diameter. But one kiln was used for bauxite sintering, the another were used for $Al(OH)_3$ calcining. At first, T/R set of 200 mA were selected for one field, both of the two processes. Soon we found the 200 mA T/R is not enough for the ESP of $Al(OH)_3$ calcining. Changed to 400 mA was still insufficient. Finally changed to 1000 mA, the working voltages can went up no more limited by the T/R rating current. The 200 mA T/R for bauxite sintering was full enough. This example means, for different gas and dust of different processes, corona current or current density, can be divers' as much as 5 folds.

For "safe", the tendency of choosing a big T/R was kept till to-day. A big current density of 0.45 mA/m^2 CE area or even more was not uncommon. Another consideration is the air load testing of the ESP erection quality. Air load current is always much bigger than gas/dust loads. But a more than necessary big T/R will induce a lot of problems:

- Small internal impedance gives unstable working especially for large ESP with big capacitance. Excess sparks occurs in ESP.
- More outer resistance or impedance is necessary for compensating the insufficient internal impedance.
- Automatic control turns worse.
- Waste money and energy.

For air load test, two parallel connected T/R sets with appropriate rating current is enough generally.

Recently we have chosen T/R rating current and numbers for a 600 MW power generating unit [7] .After analyzing the data of boilers burning similar coal with similar type and size, we choose one half number of T/R than originally design and fulfilled the ESP requirements. The current density for one square meter CE area is only 0.2 mA. So, ignore concrete condition, always select T/R with big current density is inappropriate.

5.2 Importance of Impedance

In 1979, big capacity (2Amperes) and high internal impedance (about 45%) T/Rs without external linear reactor have been imported. [12]. Although its ESP was used for collecting brown coal fly ash; generally few sparks in ESP, the strong discharge of big sparks and even arcs occurred in the ESP burning big holes on CE plates and sintering the hopper ash to blocks like red brick. This obvious shortcoming has not given rise to vigilance. Since then, in a period of about ten years, cancel the linear reactor for saving money became prevalent in China. Of course, lessons paid for electrical and mechanical failures taught us the importance of enough impedance and external linear reactor.

Lack of linear reactor and insufficient impedance give problems as excessive big T/R. Breakdown between coil lines and layers, arc burning of CE or DE and hopper sintering are its disastrous effects. Now, the T/R of appropriate inner impedance, fitted with external linear reactor get common acceptance from Chinese technicians.

Actually, early in 1978, these phenomena have already been illustrated clearly by White in his famous paper [13]. Some times from knowing to full understanding need long time practice.

6 THREE PHASE T/R

Recently some Chinese T/R companies have developed three- phase T/R and got good applications in alumina and power industries [14]. Improvements of current /voltages readings and performances have been proved by both technicians and operators. Higher cost can be compensated by benefits. Average current and/ voltage values approaching their maximum values and almost no fluctuation wave forms are its outstanding features.

We have been told in 1960's that single phase and wave form of certain degree of fluctuations is better than constant and stable wave for ESP. Peak voltage is for particle charging and average voltage for particle collecting.

Three-phase T/R is not new. We heard and denied it half century ago from books. Now, facing the fact of recognizing it, what explanations can be made?

- Higher average voltage and current, hence higher power can be put into ESP.
- Three-phase T/R is easy to induce sparks and more difficulty to control. This is the important factor of negative comments on it. But the new advanced digital control makes this shortcoming no more important.
- Much reduced primary current and balance power supply between three phases give it priorities of making large T/R.

Technical progresses always overturn old conceptions, but sometimes they also renew the old one.

7 ESP FOR CFB BOILER

Circulating Fluidized Bed (CFB) boiler became popular in China for low grade coal utilization and desulphurization purpose.

In Table 1, some typical CFB boilers in China and their desulphurization effects are listed.

Table 1 Some CFB boilers in China

Name of Power Plant	Coal sulfur (%)	Ca/S	FGD. Effi. (%)	Outlet SO_2 Concen-tration (mg/m^3)	Power Generating Capacity (MW)
Gaobei	3.12	2.4	93.7	268	100
Fenyi	0.58	2.3	81	386	100
Jining	0.76	2.3	89.3	322	135
Baiyanghe	2.4	2.2	93.8	346	135
Datun	0.75	2.2	83.74	296.7	135
Huayu	2.05	2.6	97.3	144	135
Baima	2.55	1.69	94.7	550	300
Kaiyuan	2.03	1.97	94.5	392.5	300
JEA in U.S. ˚	5.34	1.7	97.5	249	300

˚ For reference

For Chinese ESP designers, at first some of them considered due to adding limestone into CFB boiler for capture of SO_2, the ESP will working worse because of:

- Dust load increase,
- More calcium in ashes and less SO_2 and SO_3 in gas, hence the ash resistivity will be increase; then brings heavy back corona,
- .Unburnt matter in fly ash will be increased, which can hardly be collected by ESP,
- Ash may be fine and sticky, giving troubles to ESP.

Hence they increased the collecting area or SCA very much comparing to the ESP for pulverized coal boilers. Moreover, low gas velocity in ESP of $<$ 0.8m/s was selected.

But later they discovered that the performance of CFB boiler ESP did not deteriorated as much as they assumed. For example, the ESP of Baima Plant has only 4 fields, its collecting efficiency reached 99.96% and outlet dust concentration 14 mg/Nm^3–36 mg/Nm^3, even better than those ESPs for pulverized coal boilers. Meanwhile unburnt matter in Baima fly ash was only 3.65%.

The CFB boiler specialists provided new data persuade the ESP designers to modify the above misunderstandings. Table 2 listed these initial cognitions and new knowledge.

Table 2 Different understandings

Item	Initial cognitions	New knowledge
Unburnt matter in fly ash	8 wt. %	More than or less than 8 wt. % are both possible
	For all CFB boiler ESP, gas velocity should $<$ 0.8 m/s to reduce re-entrainment	Flue gas velocity is depending on the actual unburnt matter content in fly ash.
Particle size	Particle size widely distributed. Fine particles increased compare to coal powder boiler.	Fine dusts composi-tion is less because of low combustion tempe-rature in CFB boiler; giving less vapori-zation / condensation fine particulates.
Ash Resistivity	$>1\times10^{12}$ Ω·cm, due to higher Calcium and less SO_3	Most sulfur was driven out from gas by FGD effects, play no more important role. So, volume resistivity dominates the value of resistivity.

8 ESP FOR ORIMULSION® COMBUSTION

8.1 Orimulsion®

Orimulsion® is an emulsified fuel, consisting of Orinoco natural bitumen of Venezuela (70%), fresh water (30%) and a small amount of surfactant. Compared with heavy oil, it contains higher amounts of sulfur (2.85 wt. %), water, vanadium and ash (Table 3).

Table 3 Data of Orimulsion #400

Item	Unit	Sysmbol	Data
Viscosity (30□ 20 S^{-1})	mpa·s	cp	≤500
Viscosity (30□ 100 S^{-1})	mpa·s	cp	≤400
Ave. droplet size	μm	d	14 – 20
Density (15□)	g/cm^3	ρ	1.009 – 1.013
Mg	mg/L	mg	< 20
Na	mg/L	mg	< 30
V	mg/L	mg	< 360
LHV	MJ/kg	Qnet.ar	27.4 – 28.6
HHV	MJ/kg	Qnet.ar	29.6 – 31.0
Spark Point	□	—	–120
Fuel Analysis			
C	%	Car	60.2
H	%	Har	7.2
O	%	Oar	0
N	%	Nar	0.35
S	%	Sar	2.85
A	%	Aar	0.1
M	%	Mar	29.3
Dust Resistivity	Ω·cm	ρ	< 1× 10^{10}

Thus a high amount of sulfur oxide (SO_x) is created when burning Orimulsion®. Sulfur dioxide (SO_2) passes through boiler and air-preheater upstream of ESP. A few parts of it convert to sulfur trioxide (SO_3). The rate of conversion varies greatly depending on the concrete conditions. ESP for Orimulsion® Combustion is different from that for pulverized coal-fired boiler.

8.2 Injection of Ammonia

The SO_3 conversion rate for Orimulsion® is higher than for heavy oil because of high content of Vanadium (360 mg/L). Vanadium acts as catalyst for oxidation of SO_2 to SO_3. Most, if not all, of the SO_3 combine with moisture, becoming sulfuric acid (H_2SO_4) after air-preheater.

Large amount of H_2SO_4 entering ESP brings serious corrosion problem. Ammonia injection is used for prevent from steel corrosion, such as done in Zhenjiang power plant of Guangdong province.

The following chemical reactions represent what happened in the flue gas:

$$S + O_2 = SO_2$$
$$2SO_2 + O_2 = 2SO_3 \text{ } (V_2O_5 \text{ as catalyst})$$
$$SO_3 + H_2O = H_2SO_4$$
$$H_2SO_4 + NH_3 = NH_4HSO_4$$
$$NH_4HSO_4 + NH_3 = (NH_4)_2SO_4$$

The amount of low resistivity ammonium sulfate is normally much greater than fly ash, so total dusts have not high resistivity of 1×10^{10} Ω·cm.

Although submicron particles (0.1 μm–0.3 μm) of ammonium sulphate can be collected in ESP, but their strong “space charge effect” conduct to corona quenching, reducing ash collection efficiency. This phenomenon is particularly strong in the front field of ESP.

Acidic salt, NH_4HSO_4, is sticky and difficult to handle because it is easy to melting. Therefore, an excess of NH_3 is needed to ensure that $(NH_4)_2SO_4$ is generated.

Thus, by injecting ammonia into the duct before the ESP, the SO_3, which will become $(NH_4)_2SO_4$, is also collected in the ESP together with ash. The amount of ammonium sulfate is normally much greater than the fly ash and is therefore determining the characteristics of the collected ash. Key point is excessive injection of NH_3 in order to prevent from producing NH_4HSO_4. This is the reason of NH_3 escaping from outlet of ESP.

8.3 Zhanjiang Power Plant of Guangdong Province

Our first design of this ESP for Orimulsion-fired boiler in Zhanjiang Power Plant is successful [15]; but some problems such as escaping of NH_3 and untreated waste water containing NH_4 and V ions after ESP and wet FGD installation. Another method to treat Orimulsion gas also tested, for example, setting higher boiler outlet temperature and injecting MgO. More ideal method is still to be developed.

Table 4 Data of Zhanjiang Power Plant

Item	Unit	Value
Power	MW	600
Maximum continuous steam generation capacity	t/h	2,030
Fuel		Orimulsion #400
Fuel consumption at BMCR	t/h	200.36
ESP inlet flue gas quantity at BMCR	Am^3/hr, wet Nm^3/hr, dry	2,898,605 1,569,070
Flue gas temperature at ESP inlet	℃	Normal: 154 Maximum: 159 Minimum: 129
Flue gas dew point temperature	℃	149
ESP inlet dust concentration	mg/Nm^3 (dry)	1,215 (maximum)
ESP outlet dust concentration	mg/Nm^3 (dry)	40

ACKNOWLEDGEMENTS

The authors are deeply acknowledged for our colleagues and friends, with whom we have discussed thoroughly about the idea of ESP for many years. We cannot list their name here one by one; because so many experts we have discussed with and so many years passed. But we strongly remember a lot of participants of The Chinese Conference of ESP from 1st to 12th for their excellent comments and dissents.

Paragraphs on ESPs for CFB boiler and for Orimulsion combustion were written by Fu Bohe and all the other paragraphs were written by Wang Liqian.

REFERENCES

1. Experiment Report of Gas Cleaning for Fluoride Iron Ore Roasting Process in Baotou Iron & Steel Company, 1957.
2. Feldman P.L., Kumar K.S., Mullendore M.G., Fine Paticulate Agglomerator in Laminar Flow ESP, Proceedings of International Conference on Environment Production of Electric Power, Nanjing, 1996: 500-509.
3. Wang Liqian and Zhang Deren, et al. The ESP for Bauxite Sintering Rotary Kiln of Zhengzhou Aluminum Plant, Internal report, 1967.
4. Lin Hong, et al. The ESP for a 800 t/h Cement Rotary Kiln in Xiangxiang Cement Plant, Inter Report, 1977.
5. Guohua Suizhong Power Co. The Operating Problems Diagnose and Discussion Report for The ESP of No.1 Boiler, December, 2007.
6. Misaka T., Oura T. and Yamazaki M., Improvement of Reliability for Moving Electrode type Electrostatic Precipitator, Proceedings of The 10th International Conference on Electrostatic Precipitation, Paper 9A1, Cairns, Queensland, Australia, 2006.
7. Guo Ling, Wang Liqian, Ding Jinwu and Michael Zhu, Sizing and Design Experiences of the ESP for two 600 MW Power Generating Units, Proceedings of The 9th International Conference of ESP, Mpumalanga, 2004.
8. Sichun Chemical Industrial Plant & Chengdu Institute of Technology, Experiment of Electrical Rapping and Automatic Voltage Control for ESP, Chuanhua, Feb., 1966.
9. He Litang, et al. Application and Effects of ESP with Steel Brush, Proceedings of The 12th Chinese Conference for Electrostatic Precipitation, 2007: 524- 528.
10. Sun Naigeng, A New L-C Constant Current T/R Unit for ESP, Proceedings of The 6th Chinese Conference for Electrostatic Precipitation, 1995: 251-258.
11. Chen Yuyuan, Influence of Current Source Energization to the V-I Curve of ES Proceedings of The 8th Chinese Conference for Electrostatic Precipitation, 1999: 291-292.
12. Yuanbaoshan Power Plant, The Ruthmuhle ESP for a 300 MW Power Unit burn Brown Coal, Internal reports. 1978-1979.
13. White, H. J. Solving Problems in the Electrical Energization of Electrostatic Precipitators, Journal of APCA, September. 1978.
14. Xie Youjin, et al. Research and Development of Three-phase T/R sets, Proceedings of The 11th Chinese Conference for Electrostatic Precipitation, 2005: 522-525.
15. Fu Bohe, Design of Electrostatic Precipitator for Orimulsion-fired Boiler，Science & Technology Review, Vol.25, No.18, 2007: 52-55.