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LOW-GRADE COAL UTILIZATION AND PROPERTY ANALYSIS

DP/ROK/82/029

REPUBLIC OF KOREA

Technical Report *

Mission 19 April to 3 May 1986

Prepared for the Government of the Republic of Korea
by the United Nations Industrial Development Organization
acting as executing agency for the United Nations Development Programme

Based on the work of H.S. Kwon,
expert in fluidized-bed combustion (boiler design)

United Nations Industrial Development Organization
Vienna

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I. 20 T/hr AFBC Boiler Design

1. Process Design

Fuel: Anthracite culm of 2500 kcal/kg
Steam generation: 20 Tons/hr @ 13.5 atm. pressure saturated steam
Turn-down requirement: 3 to 1 in steam production

a. This type of fuel requires an extremely careful attention to the variation of fuel values. Method of storage and particle segregation substantially vary the physical characteristics of fuel from coarse to fine. The result is wide fluctuation in heating value at feeding. Imperative is to find representative sampling of the fuel with minimum and maximum range expected in heating value. Often substantial error is caused by poor sampling technique for fuel at storage. In this regard a sampling probe is recommended, as sketched in Exhibit 1. It enables one to take samples in depth in a storage pile. It usually takes care of the errors which are caused by coarse/fine particle segregation when stockpiled.

b. Criteria for process variables.

- For this type of fuel a normally claimed 20% excess air has been found to be deficient. Lack of volatiles contained in the fuel makes it harder to burn. 30% excess air is minimum. It is prudent to use the above 30% as a basis for process calculation with a margin for a higher excess air such as 40%.

- Carbon combustion efficiency for anthracite has been found to be lower than bituminous coal. 93% carbon combustion efficiency has been demonstrated. However, other mechanical considerations may limit the figure to 90%, which was recommended as a design basis. It leaves room for improving combustion efficiency with optimal design of material handling system including ash recycling.

- Fluidizing velocity is a major factor which affects not only combustion but erosion potential of the exposed steaming tubes. In fact many plants throughout the world have been experiencing severe erosion in the tubes such that tube replacement becomes necessary as often as every 3 months. It is general consensus that, the higher the velocity, the more severe tube erosion becomes. The Wilkes-Barre AFBC burning similar fuel at around 6 fps experiences no tube erosion, whereas two other plants burning softer fuel experiences severe erosion. The plants run at a velocity 20 to 30% higher than the Wilkes-Barre unit. As a result a velocity of 6 fps is recommended, although a higher velocity is advantageous in terms reducing the size of the combustor.

When erosion occurs, it is difficult to devise a means to eliminate the problem.

- Combustor temperature and gas residence time in freeboard in terms of combustion. Any fossil fuel which is extremely low in volatiles or has been artificially devolatilized is hard to burn compared with other fuel. It is especially true for fuel such as anthracite culm and petroleum coke. Any unburned carbon leaving a bubbling bed simply would not burn, unless freeboard is maintained at a sufficiently high temperature with a reasonable residence time. The temperature is the carbon ignition temperature, which is generally considered to be 750°C. Residence time of minimum 2 seconds in freeboard is necessary.

- Elutriation rate for recycle.
  If ash is captured in a convection bank as well as in a cyclone and is returned to a fluidized bed, the recycle rate is considered to be two times the fuel feed rate. If a part of the capture is bypassed, the recycle rate decreases accordingly. Ash recycle entails two important meanings; one is the possibility of reburning unburned carbon and the other is to control the bubbling bed particles to be fine for higher heat transfer. With full recycle overall heat transfer coefficient may increase to 58 Btu/hr ft^2 °F whereas no recycle can decrease it down to 45. The difference is substantial enough to warrant extreme care in providing adequate heat transfer surface area.

2. Heat and Material Balance

As a first step to plant design heat and material balance is made. The result is shown in Exhibit 2 indicating required heat distributions at full and one third load conditions. Based on design criteria of 1650°F bed temperature, 58 Btu/hr ft^2 °F for in-bed heat transfer coefficient, and a fluidizing velocity of 6 fps, bed cross-sectional area and in-bed heat transfer surface area has been calculated for full and one third load conditions. The results are tabulated in Exhibit 3. One of the major points to be addressed to is the compartmentalization of windbox for ready turn-down. Turn-down operation invariably accompanies reduction in fuel feed rate as well as combustion air rate. Cutting air rate down with full cross-section of the bed still in service can result in uneven air distribution, which would cause partial defluidization and eventual clinker formation in a fluidized bed. Compartmentalization reduces the size of the bed in service. As a result the reduction in combustion air is not translated automatically into a substantially lower fluidizing velocity. Therefore, defluidization is avoided ensuring continuous combustion of fuel in active bed.

3. Feed System Arrangement

For the size of the combustor, as indicated in Exhibit 3 and in consideration of turn-down, the most cost effective feed device is considered to be of screw feeder type. Two feed screws are recommended with turn-down capability of 6 to 1 for each screw at full load. The above capability is easy to obtain and is most widely used practice for this type of application. It covers a full load situation, when one feeder becomes disabled or one third load operation with one screw turned off. Schematics is shown in Exhibit 4 including feed bin arrangement.

One thing that commands importance is the understanding of material flow characteristics of the fuel. Depending on the shape of feed bin, material flow can be either mass-flow or funnel flow. Mono sized material of uniform chemical characteristics can be stored in a bin of either type. It presents no handling problem. In fact, cost effectiveness dictates the use of a funnel flow bin. However, in cases handling the fuel in question, it presents a serious problem.

It has been found that this type of low grade fuel is unique in distribution of fuel value in terms of size. Coarse particles tend to contain more of inert material such as silica and alumina with no heating value. Fine particles usually possess a bulk of usable heating value. If those two are segregated during handling, what the combustor may see in feed material would range from one extreme to the other. Bed temperature, as a result, may fluctuate to such an extent that sustained combustion can become all but impossible. What it indicates is that one cannot afford severe particle segregation potential which may be caused by poor design of feed bins. Caution should be exercised to ensure the feed material is not to segregate but to remain well mixed as filled.

As mentioned earlier, the two different designs implicates how material would flow. Mass flow is similar to a plug flow, which flows downward without lateral movement of material. Funnel flow drains material in the center, creating a funnel like crater, and afterwards removes material located in the outside perimeter inside the bin. When material is filled in the bin, fines tend to remain in the middle and coarses roll down toward the edge. If a funnel flow occurs, fines would be fed with high heating value. Then coarses with low heating value. Therefore creating substantial discrepancy in heat input on a hourly basis. This should be avoided. Mass flow bin is strongly recommended in order to reduce the possibility of aforementioned discrepancy.

In terms of practical bin capacity a 24 hour storage is often used. However, it implies a large bin occupying a large space vertically and horizontally. A 16-hour storage can be an alternative. Whichever should be used is to be determined after considering site specific requirements such as available space and the requirements for structure and other mechanical devices to be in place. It is not uncommon to provide a 9-hour storage capacity, if so desired.

The feed bin should be equipped with solids level sensors which indicate bin full, low for refill, and low-low for automatic slumping of the fluidized bed. Recommended type of the sensors is a paddle wheel type with a cover above it to protect it from damage.

4. Ash Recycle and System Design

Generally ash recycle is necessary in order to enhance combustion efficiency and to control bed particle size within a desirable range. However, it implies addition of mechanical devices or equipment at cost. Especially design or selection of these devices requires care mainly because of high temperature associated with recycling of hot ash. Difficulties encountered with selecting material for high temperature applications are common. At the same time differences in material behavior at elevated temperatures often lead one to improper selection of devices and material. The result could be maintenance headache at best. Frequent shut-down or abandoning the existing equipment due to poor performance is often encountered. Experience clearly indicates desire of less and simpler devices for ash recycling.

Elutriated ashes from the combustion of anthracite culm are partly captured in a convection bank and then in a mechanical collector before final clean-up in a bag filter. In terms of unburned carbon it has been found that the convection bank catch contains fairly coarse particles with relatively small quantity of unburned carbon. Whereas a bulk of unburned carbon is collected in a cyclone. This material is worth being recycled for reburning of carbon and for particle size control in a bubbling bed. Baghouse ash may experience a higher carbon content but recycling of the ash has proved no improvement in combustion or in controlling bed particle size. The ash is simply too fine and recycled ash immediately entrains the gas stream and escapes the combustor.

The experience led to a recommendation which stresses recycling of the cyclone catch only, not the convection bank ash. The convection bank ash is drained out for disposal. The scheme eliminates difficulties associated with recycling of the hot ashes without compromising the intended carbon combustion.

Recommended design of cyclone is shown in Exhibit 6. Either one single unit or two parallel units can be used. One unit design tends to be tall and combustor may have to be raised to match the elevation. Two-unit design is shorter in height but arrangement may not be simple and duct work tends to be extensive. In either case the recycled ash should be directed into "always fluidized" section of the combustor.

Due to the pressure difference between backpressure and cyclone, a positive means for pressure seal is required. A device called "trickle valve" is simple to fabricate and has been used successfully in the past. Accordingly the device is recommended. The schematics showing the devices is described in Exhibit 7.

5. Others

a. Fan Design and Selection

In general process calculations yield flow and pressure requirements for both F.D. fan and I.D. fan. Using the results calculated above would be risky, because estimated values may not necessarily be accurate. Some safety factors should be built into the proper selection of the fans. My general experience has been to add 10% margin for volume flow and 21% margin for pressure to determine test block conditions for both fans.

In addition a performance curve must be obtained from a supplier in order to determine the fan's performance at turn-down with control damper included. In general radial blade fans are used. However, other types may have different characteristics which can cause difficulties at turn-down. The difficulties may be insufficient flow at desired pressure level. Only a fan performance curve indicating position of each damper opening will provide a satisfactory answer to this question.

b. Start-up Procedure

Experience shows that a reasonably sized preheat burner cannot heat the initial bed hot enough to ignite the subject fuel. Supplementary fuel is therefore necessary. The preheat burner size was estimated to be 5 million Kcal/hr. With the burner located 0.6 m above the full load bed height and firing downward into the bed, it may be able to raise the temperature of initial bed to about 500°C. At this point a small amount of bituminous coal is fed along with full firing of oil burner to raise the bed temperature above 760°C. Anthracite culm feeding commences at this temperature.

As temperature climbs, the preheat burner firing is gradually reduced. When the bed temperature reaches a normal operating range, the preheat burner should be at minimum firing. And it is turned off. Bituminous coal feeding is replaced by anthracite culm and is eventually turned off.

II. Material Handling at 1 Ton PDU at the Center

KIER built a pilot plant to study fluidized bed combustion of low grade anthracite at the center. In-bed feeding of the fuel is currently planned and a pressure seal device has been devised for testing. Preliminary runs indicated severe degradation of the material fed and jamming of the screw device.

Review of the current design led to the following recommendations.

1. Screw flights in the hopper section have a larger conveying capacity than the downstream side flights. It should be reversed or at least have the equal capacity for both sides.
2. In terms of force exerted to the material, half pitch screw is superior to full pitch.
3. Outlet nozzle is too long to effectively discharge conveyed material and should be cut off.
4. Paddles at discharge opening are considered too long. They should be shortened and screw flights should be extended all the way to the shortened paddles. This modification in combination with the suggested change in screw flights should improve the flow of the material.
5. Also suggested was a sealed discharge screw with an uplift section coupled with an adjustable weir section as a sealing device.
6. General aspects of pneumatic conveying were discussed. Importance of phase diagrams for horizontal and vertical conveying were stressed. A method to construct the diagrams was presented.

III. Review of Two FBC Units in Operation

The two commercial units are bubbling bed at Dongchang Paper and a CFB unit at Dongyang Chemical. Both units have experienced some operational difficulties. Visits were made with the members of KIER at both plants.

1. Dongchang Paper
    a. Sloping constriction plate immediately attracted my attention. One thing that is paramount to a successful operation is uniform air distribution at each level of turn-down operations. The sloping plate entails unequal nozzle shank length, which creates unequal pressure loss. It is certain to cause uneven air distribution. The effect becomes more acute at turn-down because pressure loss is proportional to the square of air volume throughput. The resulting sluggishness of the bed can readily create local hot spots. In absence of turn-down operation, the adverse effects can be minimized.

b. The intended paper sludge feeding has not been implemented due to erroneous information on the amount of sludge. Suggestions were made to KIER to study heat balance with the required amount of sludge and then to explore the possibility of spreading sludge feed over the active bed area. Distribution of the feed material is expected to be imperative in order to avoid local cooling of the bed by water content in the sludge. In addition a series of screw conveyor for sludge transfer is a poor design at best. Maintenance can easily become a headache. Conveyor belt type would be better suited except for a metering screw.

c. Bottom ash withdrawal and classification system appeared to be extremely complex with heavy mechanical devices in place. As experience clearly indicates, material handling should be simple in order to make it workable. The plant removed a bulk of devices from the system.

d. Ash transfer system was found to be a series of mechanical drag conveyor (appeared to be Redler by Stephens-Adamson). Erosion/abrasion of the casing would be evident and frequent maintenance will become painful. Furthermore, I don't see how these devices can make pressure seal to avoid any dust blowing back into the system due to a difference in static pressure, especially at discharge of the air preheater and the bag filter. The system should have been of pneumatic conveying design. Pneumatic pipes and a mechanical blower for suction would have been sufficient to handle the ashes discharged from the bag filter and the air preheater. Ash material from these units is fine and abrasion, as often concerned with pneumatic conveying, would not be severe.

2. Dongyang Chemical

As found at Dongchang Paper, the unit also is equipped with a sloping constriction plate. For the same reason as described in item 1.a, uneven air distribution should be a problem. Modification of tuyer orifice size may reduce the problem to a certain degree. As common in a high velocity CFB unit, tube erosion and refractory failure at bottom can become serious problems. Especially the refractory is always subjected to a reducing atmosphere and corrosion in that environment will be sever, unless a proper material is used. The cyclone in this unit has a short vortex finder, which has proven to exhibit inferior collection capability. The result would be poor carbon combustion and a lower than expected heat transfer coefficient. The only way to compensate for the deficiency is to overdesign the combustor.

IV. Coal Gasification Project at KIER

The project is currently on a conceptual design stage. KIER is concerned with material feeding into a reducing atmosphere under pressure and ash withdrawal from the reactor.

1. The current concept shows an in-bed screw feeding with double lock hopper for pressure seal. In-bed feeding depends on the extent of fluidization in the bed. If it is below minimum fluidization, screw feeding into the bed would be all but impossible. At the same time, the reactor is under reducing atmosphere and a part of feed device which comes into contact with the atmosphere would experience severe corrosion.

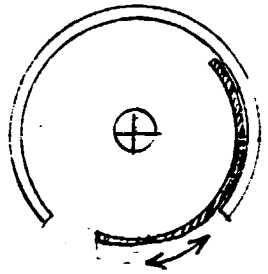
   Therefore it was recommended that the feeder be moved up to an over-bed feed position. First it will eliminate the possibility of feeder jamming which may be caused by forced feeding into a quasi stationary bed. Also subjected to only a gaseous environment with light dusting, the screw feeder can be cooled by water cooling of the shaft and corrosion potential would be reduced. Pneumatic conveying is another possibility. It can eliminate the mechanical problems mentioned above. In fact some of the pilot scale gasification projects had utilized the pneumatic conveying method. Since air is not preferred as a conveying medium due to oxygen content, other inert gases such as carbon dioxide or nitrogen should be used. Cost factor associated with the prepared inert gases can be prohibitive.

2. Ash Discharge from the Reactor

   Ash is continuously discharged from the gasifier and enters an FBC combustor where residual combustibles are burned. The resulting heat is then fed into the reactor to promote gasification process. Current concept shows a metal drain pipe leading to a feed hopper under which a screw transfers the ash to a FBC. The ash flows from a low pressure to a high pressure. As a result gas seal as well as rate control has to be satisfied. The ash is at an elevated temperature of about 700°C. Handling of hot ashes in a metal pipe can bring forth temperature related mechanical problems.

   First effective seal has to be provided. Plug flow type seal is possible, provided solids layer is high enough/ A sealed discharge screw type can be one of the plug flow type devices. However, it entails the design of screw for high temperature environment. Mechanical problems can be acute depending on the physical characteristics of the ashes. A L-valve can be an answer. It is a simple stand-pipe assisted by an air ejector. Stand-pipe acts as a seal and the air ejector as a control device for rate control. A small scale device is suggested to obtain design data for the intended ash.

Exhibit 1. Sampling Probe.



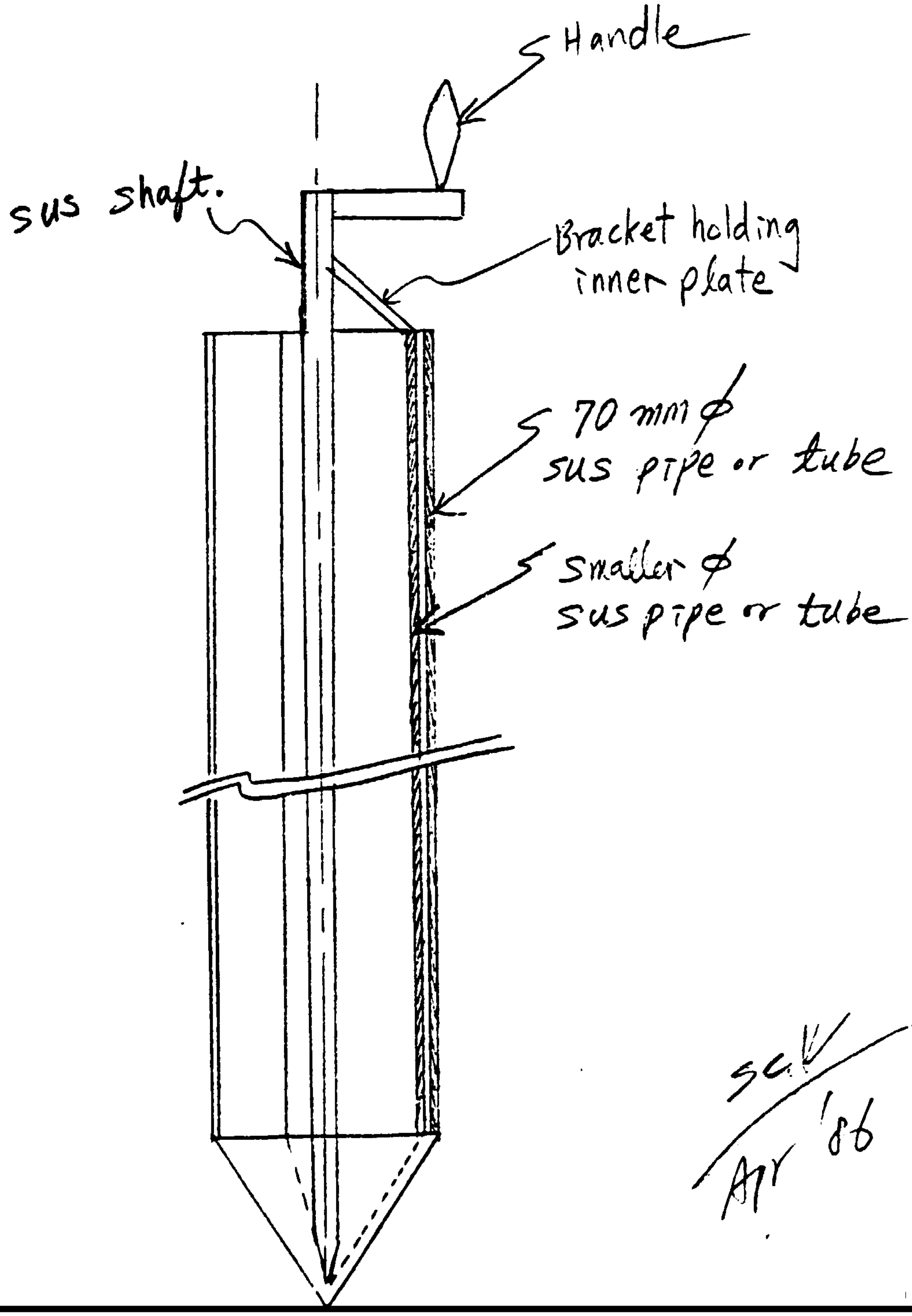


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Exhibit 2

overall 에너지 수지

	단위 kcal/hr.	Excess Air 30% full load ×10^6	Excess Air 50% 1/3 load ×10^6
	INPUTS		
1	Coal Feed Potential Heat (433)	17.27	5.003
2.	Coal feed Sensible Heat		
3.	Air Sensible Heat		
4.	Air Fan Power (210)	0.19	0.063
5	Input Total	17.46	5.066
	OUTPUTS		
6.	Potential Heat of All Solids (216)	1.21	0.350
7.	Sensible Heat of Bed Drain (189)	0.67	0.198
8.	Sensible Heat of Cyclone Collection (476 − 212)	0.	0.
9.	Sensible Heat of Baghouse Collection $(200 * \frac{432}{454+431})$	0.	0.
10.	Sensible Heat of Stack Dust $(301 * \frac{459}{454+431})$.	0.	0.
11	Heat of Sulfation (320)	−0.03	−0.007
12	Potential Heat of Flue Gas (215)	0.02	0.007
13	Gas Sensible Heat After Air Heater $(200 * \frac{431}{454+431})$.	1.23	0.409
14	Latent Heat of Combustion Moisture in Gas $(431 * 478/(100) - 430) * (582.44)$	0.36	0.103
15	Heat Losses to Surrounding: Combustor (486+223)	0.95	0.273
16	Economiser (473)	0.07.	0.019
17	Cyclone (475+476−212)	0.30	0.074
18	Air preheater (201)	0.11	0.036
19	Heat Absorbed by Water/Steam: In-bed (224) A/P included	6.74 ✓	1.925 ✓
20	Freeboard (487)	1.54 ✓	0.447
21	~~Economizer~~r (474) convection bank	4.29 ✓	1.234
22	Total Output	17.46	5.068
23	Combustion Efficiency, 1 − (L6 + L12)/L1	0.929	0.929
24	Overall Boiler Efficiency (L19+L20+L21)/L5	0.720	0.712

Subject: 물질수지 . 단위 Kg/hr

INPUTS	Full load	1/3 load
Coal Feed (128)	6846	1984
Combustion Air (129+130)	34493	11531
Total Input	41339	13515
OUTPUTS		
Bed Drain (156)	4272	1259
Cyclone Collection (153 * (1-REC/100))	0	0
Baghouse Collection (158)	139.9	19.8
Stack Dust (159)	0.1	0.0
Flue Gas (131)	36926	12236
Total Output	41338	13515

116640 m^3/hr @ 900°C

1944 m^3/min

32.4 m^3/sec

18 m^2/ area

INBED HEAT BALANCE. 단위 kcal/hr

	INPUTS	full load ×10⁶	1/3 load ×10⁶
1	coal (208)	17.266	5.003
2	Air Preheater (209)	1.736 ✓ 50 - 260°C	0.524
3	Fan Power (210)	0.189 27-50	0.063
4	Moisture (211)	0.258	0.086
5	Reinjection (212)	0.952	0.135
6	Sensible Heat of Coal (213)	0.	0.
7	Input Total (214)	20.401	5.871

5

	OUTPUTS	full load ×10⁶	1/3 load ×10⁶
8	Potential Heat of Flue Gas (215)	0.023	0.007
9	Potential Heat of Ash (216)	1.207	0.350
10	Latent Heat of Flue Gas at 80F (217)	0.613	0.189
11	Sensible Heat of flue + Dust (218)	10.633 @900°C	3.053
12	Sensible Heat of Bed Drain (219)	0.672	0.198
13	Sulfation Heat (220)	-0.025	-0.007
14	Output Total (221)	13.123	3.793
15	Input - Output (222)	3% loss 7.278	2.078
16	Heat loss (L15×0.074) (223)	0.538 Rad	0.154
17	Inbed Heat Transfer (224)	6.740	1.924

0.15

+

FREEBOARD COMBUSTION CONSIDERATION : 5% of TOTAL COMBUSTION

18	Input Total (L7 - L1×0.05)	19.538	5.621	
19	Output Total (L14 + L1×0.05)	~~13.985~~ 13.123	4.043 -0.25 = 3.8	
20	Input - Output (L18 - L19)	~~5.552~~ 6.415	1.578	1.82
21	Heat Loss (L20×0.074)	~~0.411~~ 0.4747	0.117	
22	Inbed Heat Transfer (L20 - L21)	~~5.141~~ 5.94	1.461	1.68

Exhibit 3 Req'd Heat Transfer Surface

Bed Area	$6^m \times 3^m$	$4.5^m \times 4^m$
Full load		
Req'd Heat Absorption	6.74×10^6 kcal/hr	6.74×10^6 kcal/hr
Req'd In-bed H.T. Surface *1	$34.1\ m^2$	$34.1\ m^2$
Bed Height	1.2 m	1.2 m
Splash Zone	0.45 m	0.45 m
Wall Area	$21.6\ m^2$	$20.4\ m^2$
Splash Zone	$8.1\ m^2$	$7.85\ m^2$
In-bed Tube area	$4.4 m^2$ (14 tubes)	$5.85\ m^2$
Fluidizing Velocity	1.8 m/s	1.8 m/s
1/3 Load		
Req'd Heat Absorption	1.924×10^6 kcal/hr	1.924×10^6 kcal/hr
Req'd In-bed H.T. surface *1.	$9.74\ m^2$	$9.74\ m^2$
Bed Height *2	0.7 m	0.78 m
Splash Zone	0.3 m	0.3 m
Fluidizing velocity	1.0 m/s	1.0 m/s

*1. Based on Projected Area and 58 ~ 60 Btu/hr ft² °F. The projected area is not true area based on curved wall surface area, which is 30 % larger. Therefore H.T.C of 30% less can be taken care of.

*2. Splash at slumping of partial bed lowers the active bed height.

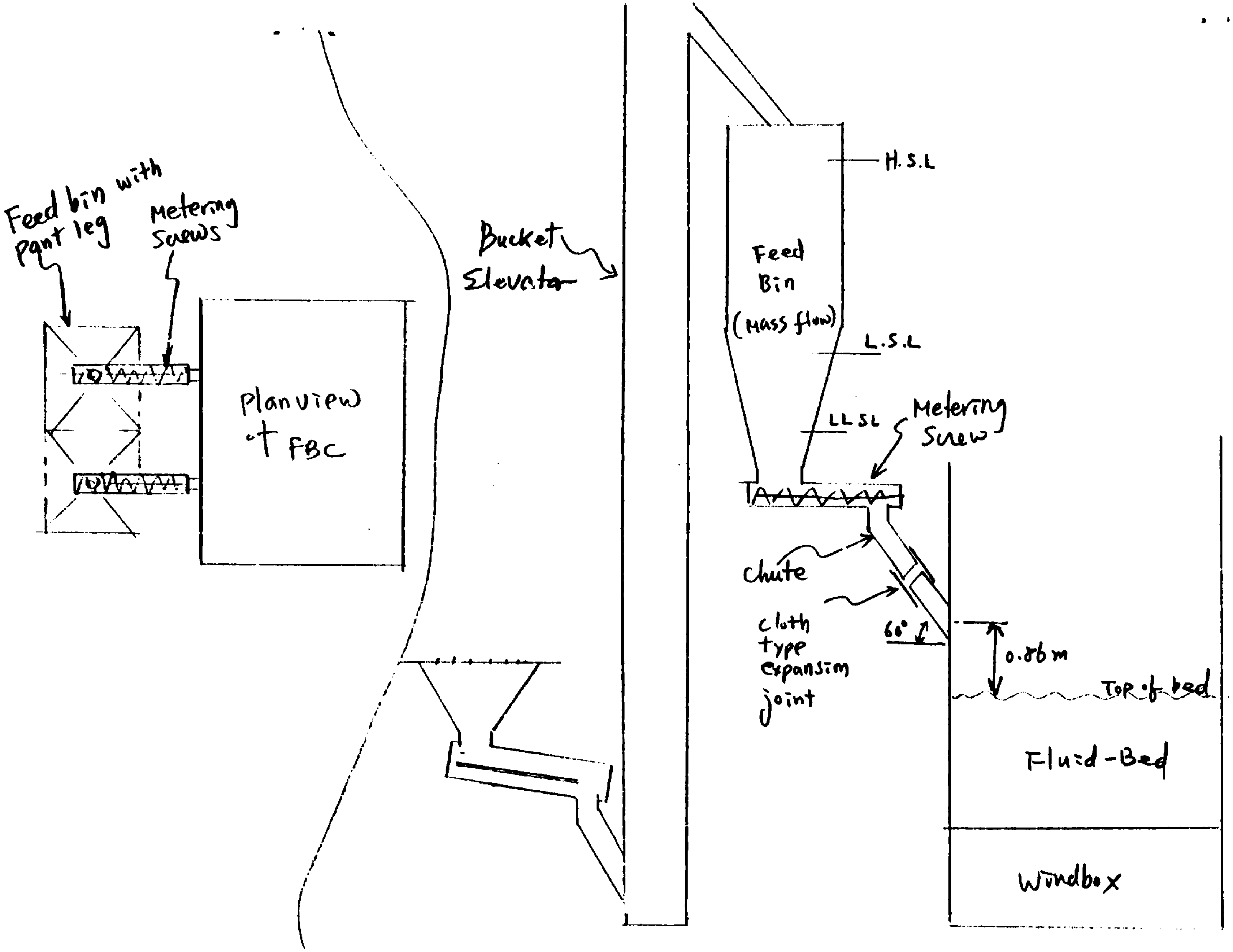

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Exhibit 4. Feed System Arrangement and Screw feeders

Exhibit 5. Possible Design for 16 hr storage bin

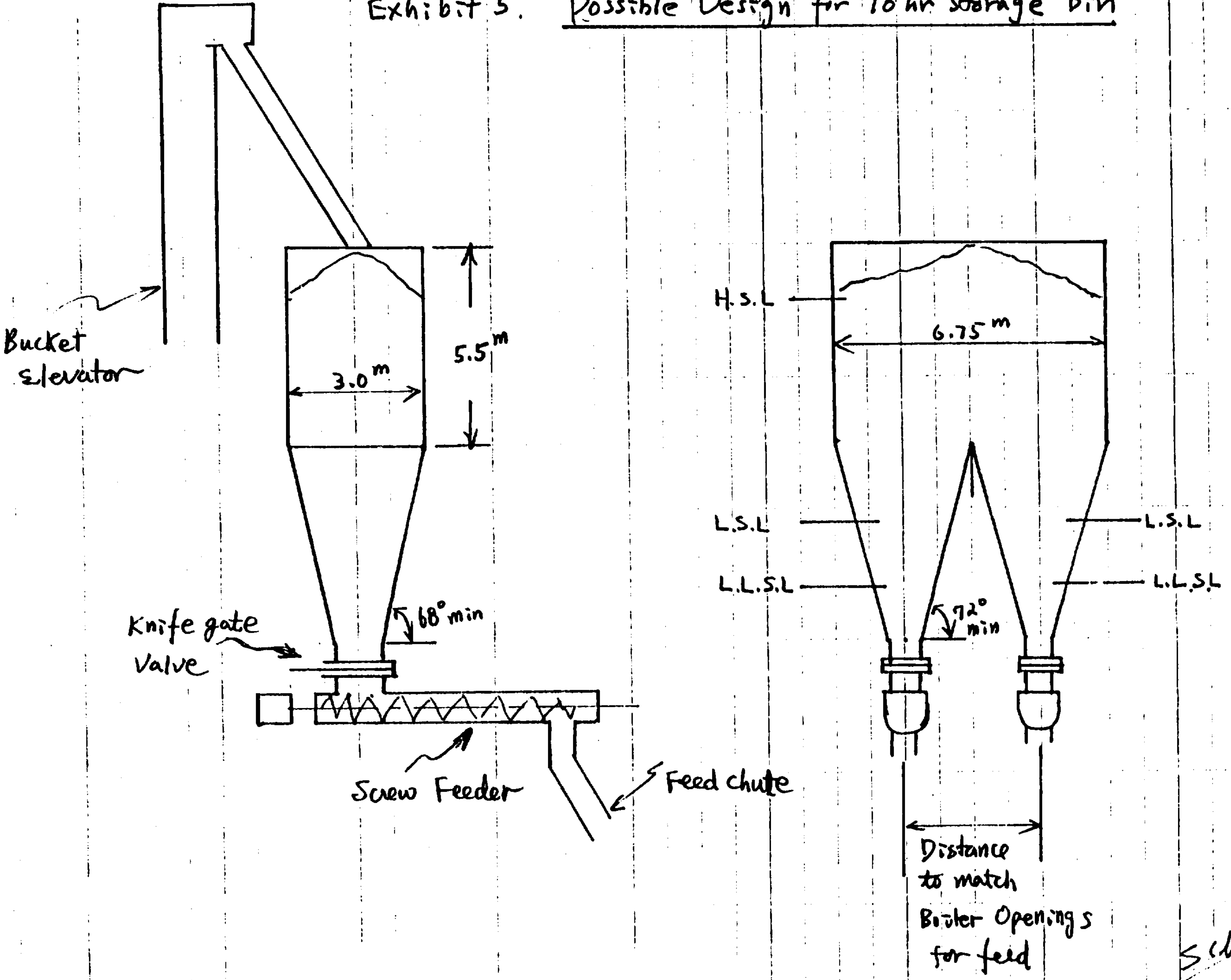
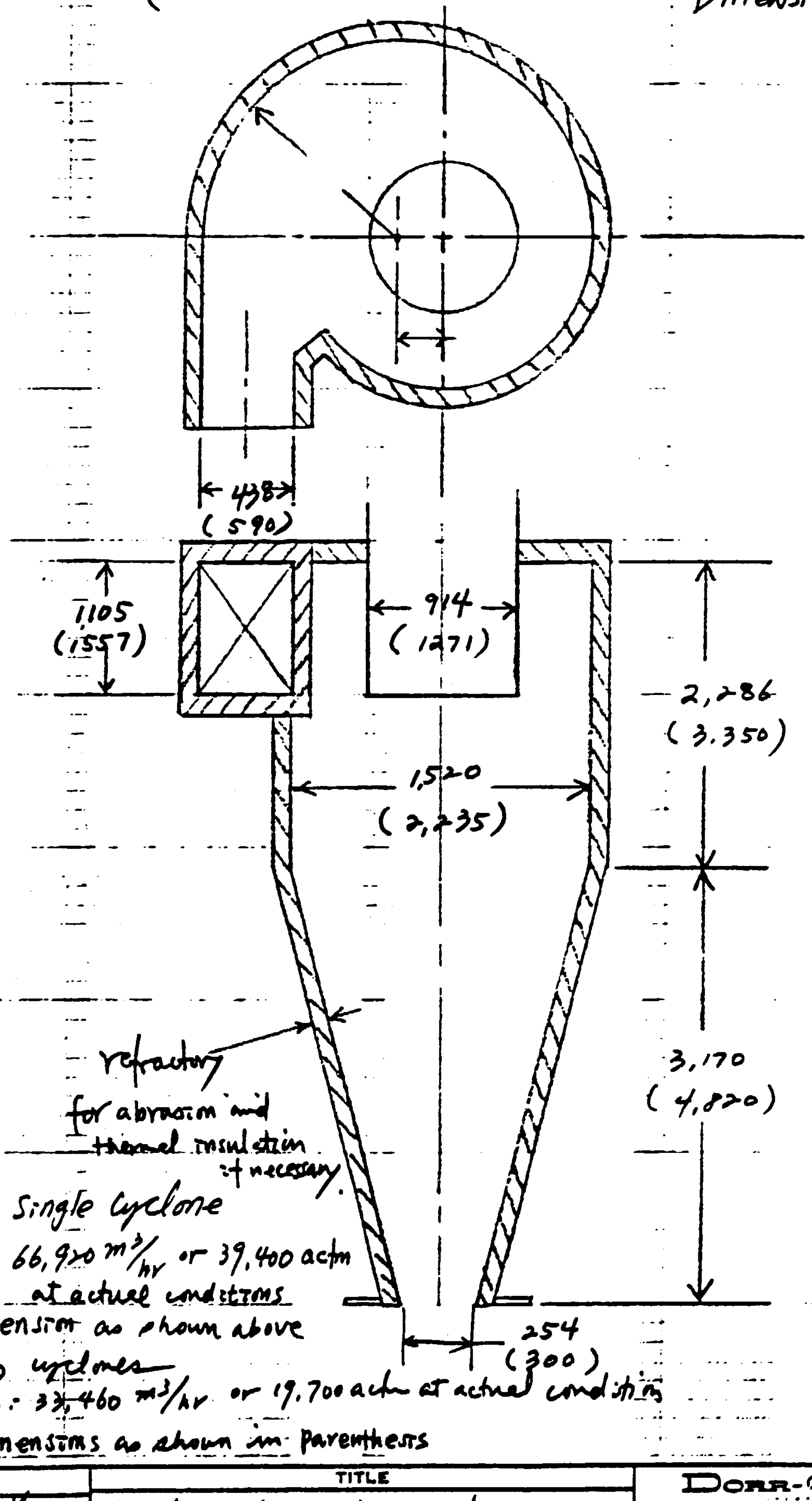


Exhibit 6. Cyclone Design
(one Unit or Two units)

DIMENSIONS in MM



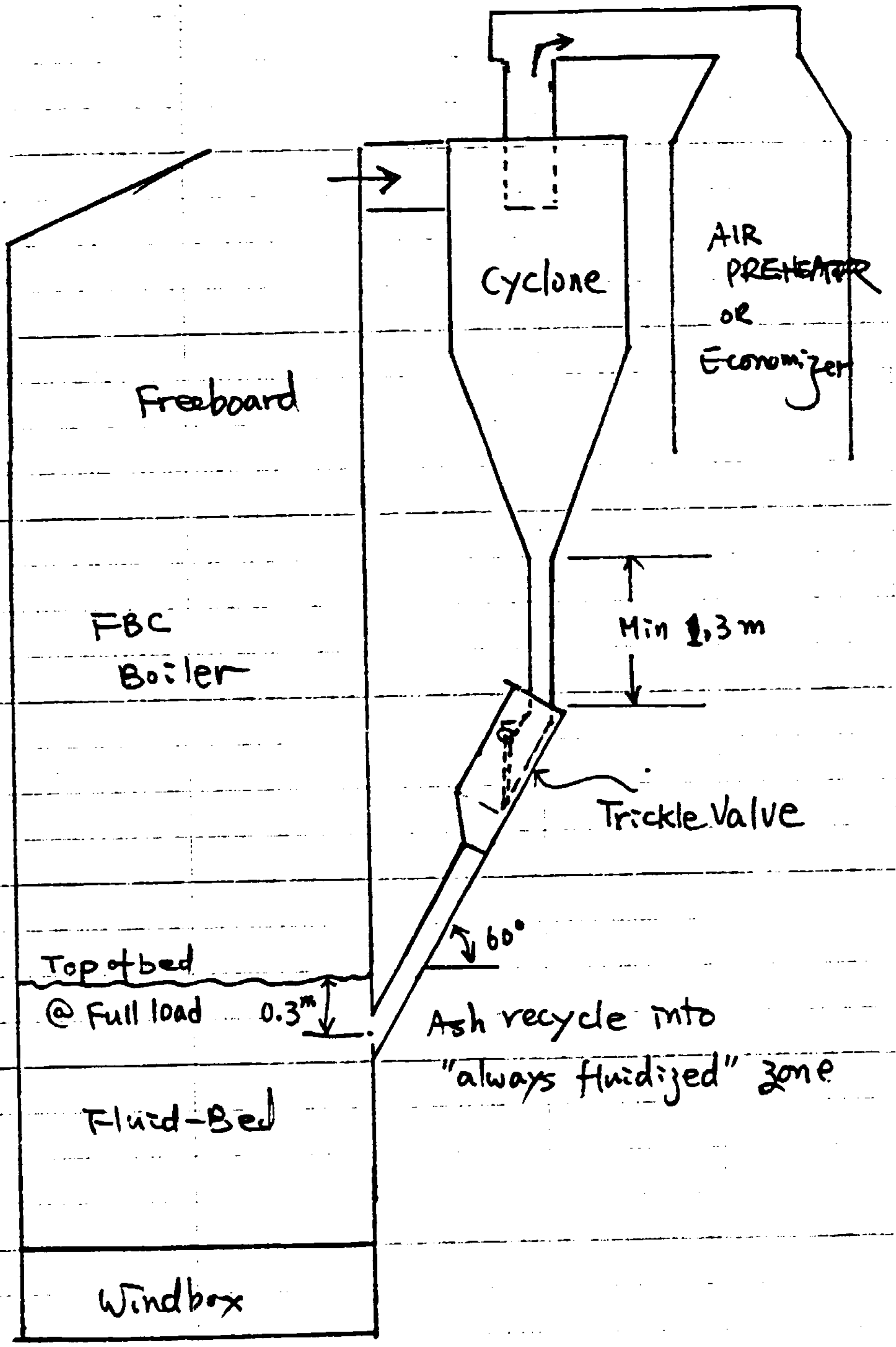
1. One Single cyclone
   Gas 66,920 m^3/hr or 39,400 acfm
   at actual conditions
   Dimension as shown above
2. Two cyclones
   Gas: 33,460 m^3/hr or 19,700 acfm at actual conditions
   Dimensions as shown in parenthesis

SCALE:
BY: S.C.K
DATE:

TITLE
Cyclone for ash recycle

DORR-OLIVER
SK.

Exhibit 7. Ash Recycle thru Trickle Valve



BcK