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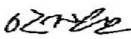
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POWER ISLAND PACKAGE SUPPLIER  SOJITZ CORPORATION	 DAELIM INDUSTRIAL CO., LTD.
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PROJECT TITLE THAI BINH 2 THERMAL POWER PLANT 2 x 600MW

DRAWING / DOCUMENT TITLE SCR OF CATALYST VOLUME CALCULATION SHEET

Vendor's Logo: 	FUNCTION	NAME	SIGN	DATE
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P.O NO.	110180-29-124-001-A01
ITEM NO.	124
ITEM DESCRIPTION	De-Nox System
DOCUMENT NO.	TB2-SDC.VP124-00HTA-M-M1A-CAL-0002
DOCUMENT TITLE	SCR OF CATALYST VOLUME CALCULATION SHEET
REV NO.	A

Daelim's Approval Status

Daelim Industrial Co., Ltd.	
Job No.	110180
	A - APPROVED
	B - APPROVED WITH COMMENTS
	C - RETURNED FOR CORRECTION
	D - REJECTED
	N - NOT APPLICABLE(REFERENCE ONLY)
SIGNED BY : _____ DATE : _____	
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VENDOR'S LOGO:



1. Calculation Basis

The catalyst volume is calculated based on the BMCR worst coal Load conditions. DeNOx efficiency is 54.6% and ammonia slip is 2 ppmd @ 6% O₂.

2. Calculation model

The model for calculating the necessary catalyst volume is based on a 1st-order rate constant, K_{NH_3} , in the conversion of NH₃. The reason for considering NH₃ in the DeNOx reaction is that this is the limiting component, i.e. is rate determining, since the NH₃/NOx ratio is less than 1. A 1st-order reaction means that the reaction rate is directly proportional to the concentration of ammonia in the flue gas.

The DeNOx reactions occur on the outer surface of the catalyst. This means that the rate of reaction is proportional to the total catalyst surface area, A, and reverse proportional the flue gas flow rate, F:

$$-r_{NH_3} = K_{NH_3} \times A/F \times C_{NH_3}$$

The rate constant K_{NH_3} depends primarily on the temperature and the catalyst type and age but the flow conditions in the catalyst (linear velocity) also have some influence.

The rate equation can be integrated over the entire catalyst volume¹ to:

$$\ln(1 - X_{NH_3}) = -K_{NH_3} \frac{A}{F}$$

in which X is the fractional conversion of NH₃:

$$X_{NH_3} = \frac{c^{in} - c^{out}}{c^{in}}$$

Rearranging yields:

$$\frac{F}{A} = NHAV = \frac{-K_{NH_3}}{\ln(1 - X_{NH_3})}$$

in which NHAV is the so-called Normal Hourly Area Velocity (Nm³/m²/hr) defined as F/A. A is total catalyst surface area, i.e. catalyst volume multiplied by A_{cat} where A_{cat} is the specific surface area of the catalyst.

¹ For details please refer to text books on chemical reaction kinetics

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It should be noted that for SCR DeNO_x, area velocity, NHA_V, is used rather than space velocity. This is because, as mentioned above, the NO_x conversion occurs on the catalyst surface.

The rate constant K_{NH_3} has to be corrected for the diffusion resistance from the bulk gas phase to the catalyst surface. This is done by considering it composed of two parts: the diffusion rate expressed by k_g and the surface reaction rate k_s . Furthermore it has to be corrected for deactivation over the life of the catalyst by the correction factor $f_{EOR \text{ activity}}$:

$$K_{NH_3} = \frac{1}{\left(\frac{1}{k_{\text{surface}}} + \frac{1}{k_g} \right)} * f_{EOR \text{ activity}}$$

It is unavoidable that the mixing of ammonia into the flue gas has some inhomogeneity and that the flue gas flow rate is not entirely uniform in the reactor cross section. This means that the necessary catalyst volume becomes somewhat larger than the 'ideal' volume, i.e. the volume for perfect mixing and ideal flow conditions. These deviations are expressed by the correction factors $f_{NH_3, \text{mal}}$ and $f_{\text{gas, mal}}$.

Thus, in overall:

$$\text{Catalyst Volume} = \frac{F}{NHA_V * A_{\text{cat}} * f_{NH_3, \text{mal}} * f_{\text{gas, mal}}}$$

- $f_{NH_3, \text{mal}}$ is the calculated ammonia maldistribution factor, which corrects for a non-ideal distribution of NH₃ and NO_x in the flue gas. It depends mainly on the type of ammonia injection system (grid or mixer) and the NO_x distribution from the boiler
- $f_{\text{gas, mal}}$ is the calculated gas maldistribution factor, which corrects for a none-ideal distribution of the flue gas at the inlet to the first catalyst layer.
- $f_{EOR \text{ activity}}$ is the relative activity at the end of the guarantee period. It is calculated based on the type of fuel used in the boiler.
- k_{surface} is the surface activity of the catalyst. It depends on
 - NO_x content
 - NH₃/NO_x-ratio
 - Gas composition (O₂, H₂O, etc)
 - Temperature

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- Pressure
- Catalyst type (chemical composition, porosity, wall thickness)
- k_g is the mass transfer coefficient. It is calculated in Topsøe's computer program using fluid dynamic models. It depends on:
 - The linear velocity of the gas in catalyst channels, hydraulic diameter² (catalyst channel size) and length of catalyst element
 - Flow pattern in the catalyst channel (turbulent, laminar, mixed)
 - Temperature and gas composition

The calculation of the correction factors $f_{NH_3, mal}$ and $f_{gas, mal}$ is done using Topsøe's proprietary computer programs. Described very simplified, a large number of simulations are run with ammonia-to-NOx ratios varying around the average. The average performance of these simulations is compared to performance with no variation and the deviation is expressed as a correction factor, $f_{NH_3, mal}$. The same is done with the flue gas flow rate varying around the average to obtain $f_{gas, mal}$. It is not possible to perform these calculations manually.

In case the ammonia to NOx ratio is much less than 1, a $\pm 10\%$ variation has very little impact on performance and in such case $f_{NH_3, mal} \approx 1$.

² The size of the channel openings of the special wave shaped structure of DNX[®] catalysts is described by use of a term from fluid dynamics: hydraulic diameter. The hydraulic diameter, D_h , is defined as:

$$D_h = 4 \times \frac{\text{Channel cross section area}}{\text{Channel perimeter length}}$$

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3. Catalyst volume calculation

3.1 Design parameters

Parameter	BMCR Worst coal
Gas flow rate, F, Nm ³ /hr	939,655
Temp., °C	392
NO _x ⁱⁿ , ppm dry / dry @6% O ₂	598 / 536
NO _x ^{out} , ppm dry @6% O ₂	243
A _{cat} , m ² /m ³	405
k _{surface}	175.47
k _g	80.13
f _{NH3, mal}	1.0
f _{gas, mal}	0.9691
f _{EOR}	0.7395
X _{NH3}	0.9932
K _{NH3}	40.68
NHAV, Nm ³ /m ² /h	8.15
Catalyst volume, m ³	293.8
Offered volume, m ³	297.56

Calc. no 1557425

The values of k_{surface}, k_g, f_{NH3, mal} and f_{gas, mal} are calculated on Topsøe's advanced in-house computer program.

The NH₃/NO_x ratio is 0.5497 « 1.0 and therefore f_{NH3, mal} = 1

The values of X_{NH3}, K_{NH3}, NHAV and catalyst volume are calculated according to the formulas above.

With NH₃/NO_x ratio = 0.5497 the inlet ammonia concentration is 536×0.5497 = 294.6 ppm dry @6% O₂. The outlet concentration of NH₃ (the ammonia slip) is 2 ppm dry @6% O₂. The ammonia conversion thus is:

$$X_{NH3} = \frac{294.6 - 2.0}{294.6} = 0.9932$$

The rate constant:

$$K_{NH3} = \frac{1}{\left(\frac{1}{175.47} + \frac{1}{80.13} \right)} * 0.7395 = 40.68$$

and then

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$$NHAV = \frac{-40.68}{\ln(1 - 0.9932)} = 8.15$$

And finally

$$Catalyst\ Volume = \frac{939,655}{8.15 * 405 * 1.0 * 0.9691} = 293.8$$

3.2 Conclusion

The calculated volume is less than 297 m³. Thus the offered volume of 297.56 m³ is suitable.

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4. Reaction stoichiometry and ammonia consumption

The catalyst volume and the NH₃ consumption are based on the following reactions:



i.e. a 1:1 stoichiometric reaction ratio between NH₃ and NOx.

The ammonia consumption (100 % NH₃) is calculated from:

$$\text{NH}_3 \text{ consumption (kg/hr)} = \text{Flow} \times (\text{NOx}^{\text{in}} \times \% \text{DeNOx} / 100 + \text{NH}_3 \text{ slip}) / 22.414 / 10^6 \times 17.0$$

Flow is Nm³/hr on wet basis. NOxⁱⁿ and NH₃ slip are ppm on wet, actual O₂ basis.

5. Catalyst Data

<u>Physical properties</u>	
Wall thickness, mm	0.8
Channel hydraulic diameter, mm	7.9
Cell pitch, mm	10.0
Plate pitch, mm	9.1
Cell density, CPSI	7.1
Specific area m ² /m ³	405
Open area (void), %	80
Leading edge reinforcement	Yes
<u>Chemical composition</u>	
Vanadium pentoxide, %	0.1 - 4
Tungsten trioxide, %	1 - 7
Silicon dioxide, %	15 - 25
Kaolin, %	13 - 23
Titanium dioxide, %	40 - 50
Fibres	8 - 12
<u>Element sizes</u>	
Element cross section including metal frame, mm x mm	466 x 466
Element height, mm	322 / 342 / 572 / 612
Net catalyst depth, mm	250 / 270 / 500 / 540

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5.1 Reactor data

Parameter	Design
Catalyst type	DNX-XD
Total catalyst volume 2 units, m ³	1,190.24
Catalyst volume per unit, m ³	595.12
Number of reactors per unit	2
Catalyst volume per reactor, m ³	297.56
Net catalyst depth, total, mm	2,250
Number of layers	3+1
Reactor dimensions (L × W), m	14 × 10
Module size (L × W × H), mm (drawing number)	VE422AH: 1,880 × 946 × 1,356 VE522AH: 2,346 × 946 × 1,356 VE432AH: 1,880 × 1,410 × 1,356 VE532AH: 2,346 × 1,410 × 1,356
Module weight, kg	VE422AH: 566 VE522AH: 703 VE432AH: 850 VE532AH: 1065
Approx. total weight of all modules per reactor (3 layers), tonnes	129.1

Note: Catalyst geometry

