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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
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Research Triangle Park, North Carolina 27711

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by

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1.0 BACKGROUND AND PURPOSE

The existing New Source Performance Standard (NSPS) for SO_2 emissions from coal-fired steam generators is 0.52 g SO_2/MJ (1.2 lb $SO_2/10^6$ Btu) of heat input. Depending on coal sulfur content and heating value, compliance with this standard can be achieved by means of flue gas desulfurization (FGD), coal desulfurization, the use of low sulfur coal, or a combination of these approaches. Since the promulgation of the SO_2 NSPS in 1971, improvements have been made in the performance and reliability of FGD processes. Because of these improvements, public interest groups have requested that the EPA promulgate more stringent SO_2 emission standards. Therefore, the EPA's Office of Air Quality Planning and Standards (OAQPS) has undertaken a program to review the existing NSPS. The study described in this report was done to assist OAQPS in the review by providing information on the energy requirements of SO_2 control systems. The report answers the following questions.

What are the amounts and types of energy required to operate various SO_2 emission control systems?

How do these energy requirements compare to those of steam generators without emission control systems?

How do projected energy requirements for emission control compare with projected national energy demands in 1987 and 1997?

2.0 APPROACH

The study was based on an EPA model including 102 systems which are combinations of power plants and SO_2 control methods. The variables considered in the model are level of SO_2 control, method of SO_2 control, power plant size, and coal composition. The levels of each variable considered in this study and the combinations of variables were defined by EPA as shown in Table 1. Three levels of SO_2 control were considered. They include the existing NSPS (0.52 g SO_2/MJ heat input), 90 percent SO_2 removal, and 0.22 g SO_2/MJ. Control methods considered include regenerable FGD processes, nonregenerable FGD processes, transportation of low sulfur coal to the Midwest, and a combination of coal cleaning and nonregenerable FGD processes.

Energy requirements for the 102 model systems were calculated by extrapolating base case energy requirements. Base case energy requirements for each SO_2 control method were calculated from material and energy balances. The base case was 90 percent SO_2 removal from the flue gas of a 500 MW power plant burning 3.5 percent sulfur coal. Extrapolation factors which describe energy requirements in terms of flue gas rate and SO_2 removed were defined. The extrapolation factors were used to calculate energy requirements for all the power plant/SO_2 control system combinations included in the model.

TABLE 1. MODEL SO_2 EMISSION CONTROL SYSTEMS STUDIED

SO_2 Control Level	Plant Sizes Considered, MW	FGD Processes Considered*	Coal
0.52 g SO_2/MJ (1.2 lb $SO_2/10^6$ Btu)	25, 100, 500, 1000	LS, L, MgO, W-L/A, D-A	3.5% sulfur; 27.9 MJ/kg
	25, 100, 500, 1000	LS, L	7.0% sulfur; 27.9 MJ/kg
	25, 500	---	0.6% sulfur; 20.9 MJ/kg western coal transported to a Midwest power plant
	25, 500	---	0.8% sulfur; 25.6 MJ/kg western coal transported to a Midwest power plant
	500	LS, L	2.3% sulfur; 29.2 MJ/kg **
90% SO_2 Removal by FGD	25, 100, 500, 1000	LS, L, MgO, W-L/A, D-A	3.5% sulfur; 27.9 MJ/kg
	25, 100, 500, 1000	LS, L, MgO, W-L/A, D-A	7.0% sulfur; 27.9 MJ/kg
	25, 100, 500	LS, L	0.8% sulfur; 20.9 MJ/kg
	25, 100, 500	LS, L	0.8% sulfur; 25.6 MJ/kg
0.22 g SO_2/MJ (0.5 lb $SO_2/10^6$ Btu)	25, 500	LS, L	0.8% sulfur, 20.9 MJ/kg
	25, 500	LS, L	0.8% sulfur; 25.6 MJ/kg
	25, 500	LS, L	2.3% sulfur; 29.2 MJ/kg**
	25, 500	LS, L	4.6% sulfur; 29.2 MJ/kg***

*LS = Limestone
L = Lime
MgO = Magnesia Slurry
W-L/A = Wellman-Lord/Allied
D-A = Double-Alkali

**Physically cleaned 3.5% sulfur; 27.9 MJ/kg coal (40% sulfur removal)

***Physically cleaned 7.0% sulfur; 27.9 MJ/kg coal (40% sulfur removal)

3.0 SUMMARY OF RESULTS

The results of the study show how energy requirements depend on SO_2 control method, level of control, and coal sulfur content. It was found that energy requirements for SO_2 control systems (expressed as energy required per unit of electrical generating capacity) depend only slightly on plant size.

3.1 Design Assumptions

The energy requirements for operating flue gas desulfurization systems were calculated based on the process designs summarized in Table 2. The design assumptions for coal cleaning processes are shown in Table 3. A unit train consisting of 100 coal cars and five locomotives was the design basis for coal transportation. Fuel consumption rates, transport distance, train speeds at full and reduced power, and coal dust blow-off losses were specified.

Table 4 shows calculated energy requirements for the six processing operations in FGD systems. Particulate/chloride removal, reheaters, and fans account for 65 to 90 percent ot total energy requirements for nonregenerable FGD processes. Sulfur recovery operations account for the majority of energy requirements for regenerable FGD processes.

3.2 Comparison by SO_2 Control Methods

Figure 1 shows the energy required to meet the existing NSPS of 0.52g SO_2/MJ using different SO_2 control methods for several coal compositions. The total energy requirements are

TABLE 2. PROCESS DESIGN BASES FOR FGD PROCESSES*

Process Step	FGD Process				
	Limestone	Lime	MgO	Wellman-Lord/Allied	Double-Alkali
Particulate/Chloride Removal	Venturi	Venturi	Venturi	Venturi	Venturi
SO_2 Scrubbing	Mobile Bed	Mobile Bed	Venturi	Valve Tray	Mobile Bed
Reheat	Indirect Steam Reheater	Indirect Steam Reheater	Indirect Steam Reheater	Indirect Steam Reheater	Indirect Steam Reheater
Fans	Induced Draft Fans	Induced Draft Fans	Induced Draft Fans	Induced Draft Fans	Induced Draft Fans
Sulfur Disposal/Recovery	Lined Settling Pond	Lined Settling Pond	Production of Sulfuric Acid	Production of Elemental Sulfur	Lined Settling Pond

*Selection of processing techniques was based on data from the open literature which were representative of commercially available systems.

separated into the types of energy required, i.e., steam, fuel oil, natural gas, electricity, and coal losses. Nonregenerable FGD processes impose the lowest energy requirements. The combination of coal cleaning and nonregenerable FGD systems requires three times the energy required by the FGD process alone. Transportation of low sulfur western coal to the Midwest requires 25 to 100 percent more energy than combusting a high sulfur eastern coal and using a nonregenerable FGD process.

TABLE 3. DESIGN ASSUMPTIONS FOR PHYSICAL COAL CLEANING FACILITY

- 40% sulfur removal
- 95% energy recovery efficiency
- The electric power requirements for a 278 kg/s (500 ton/hr) cleaning plant are 2980 kW.
- The heat duty of a thermal dryer is 534 kJ/kg (230 Btu/lb) of coal dried.
- One half of the clean coal product (the coal fines) is thermally dried.
- Heat for the thermal dryers is supplied by burning a portion of the clean coal product.
- 50% of the ash content of the coal is removed.
- The average heating value of the clean coal is 29.2 MJ/kg (12,500 Btu/lb).

Figure 2 shows the energy required to meet a standard of 90% SO_2 removal using different SO_2 control methods for several coal compositions. Figure 3 shows energy requirements for meeting a standard of 0.22 g SO_2/MJ. The energy requirements for different

TABLE 4. ENERGY REQUIREMENTS FOR THE PROCESSING OPERATIONS IN FGD SYSTEMS

		Energy Requirements for Flue Gas Desulfurization, MJ/s						
FGD Process	Coal Sulfur Content	Raw Material Handling and Preparation	Particulate/ Chloride Removal	SO_2 Scrubbing	Reheat	Fans	Sulfur Recovery/ Disposal	Total System Energy Requirements**
Limestone	3.5%	2.2	9.0*	8.8	18.3	10.4*	0.3	49.2
	7.0%	4.4	9.0*	13.5	18.5	11.1*	0.6	57.3
Lime	3.5%	0.2	9.0*	6.3	18.3	10.2*	0.3	44.3
	7.0%	0.4	9.0*	9.4	18.3	10.4*	0.5	48.2
Magnesia Slurry	3.5%	0.5	3.0	2.5	15.3	14.7	41.1	77.5
	7.0%	0.9	3.0	5.0	15.4	16.1	82.8	124
Wellman-Lord/Allied	3.5%	0.2	3.0	0.9	16.8	18.3	136	176
	7.0%	0.3	3.1	0.9	17.3	18.8	281	321
Double-Alkali	3.5%	0.3	3.0	2.4	18.2	14.9	0.7	39.8
	7.0%	0.5	3.0	2.4	18.2	14.9	1.3	40.7

*Energy required by fans to overcome pressure drop associated with particulate removal is included in the particulate removal operation.
**Utilities and Services for the FGD processes account for the discrepancies in system totals.

Assumptions

500 MW power plant (net generating capacity)
90% SO_2 removal
Uncontrolled power plant net heat rate = 2640 J/kW-s
Steam produced in Magnesia Slurry and Wellman-Lord/Allied process is used within the process.
Magnesia Slurry process produces sulfuric acid as a by-product.
Wellman-Lord/Allied process produces sulfur as a by-product.

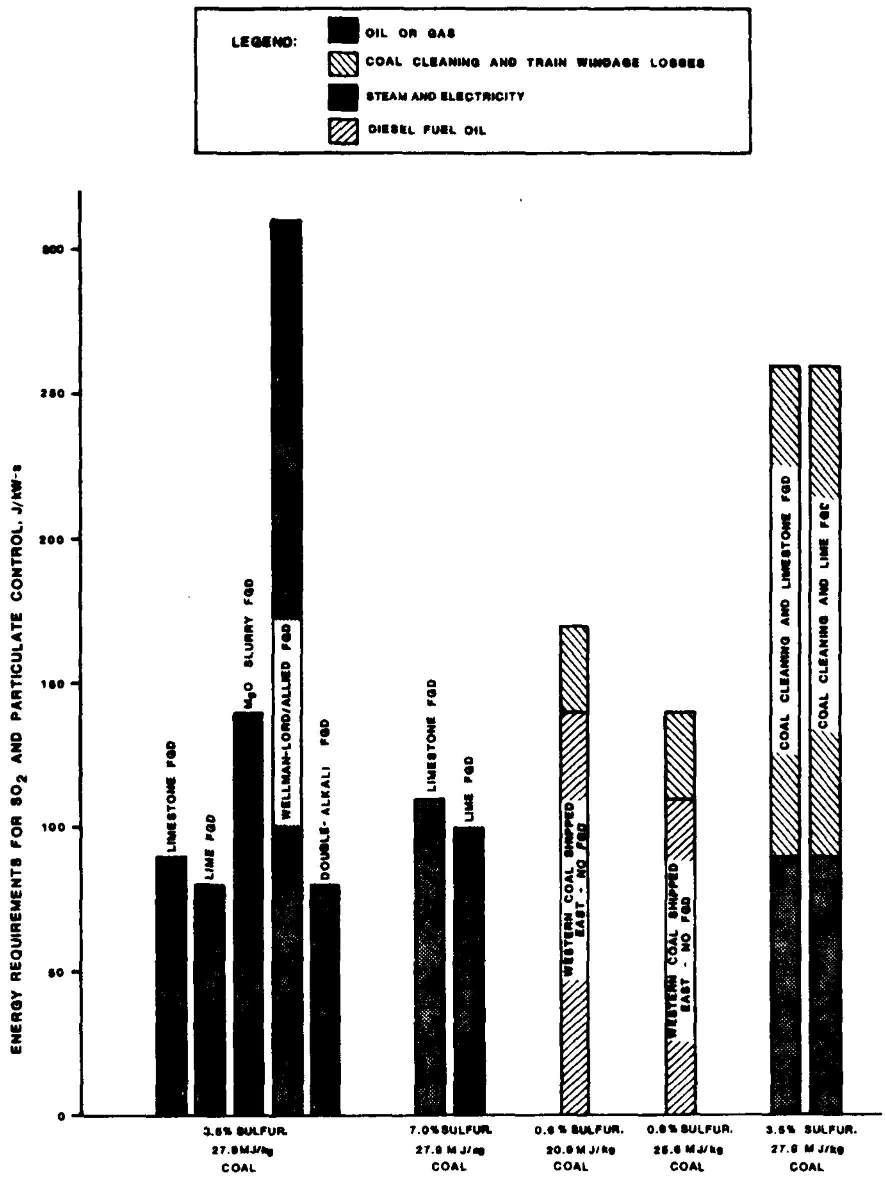

Figure 1. Energy requirements for SO_2 and particulate control - 0.52g SO_2/MJ control level, 500 MW plant.

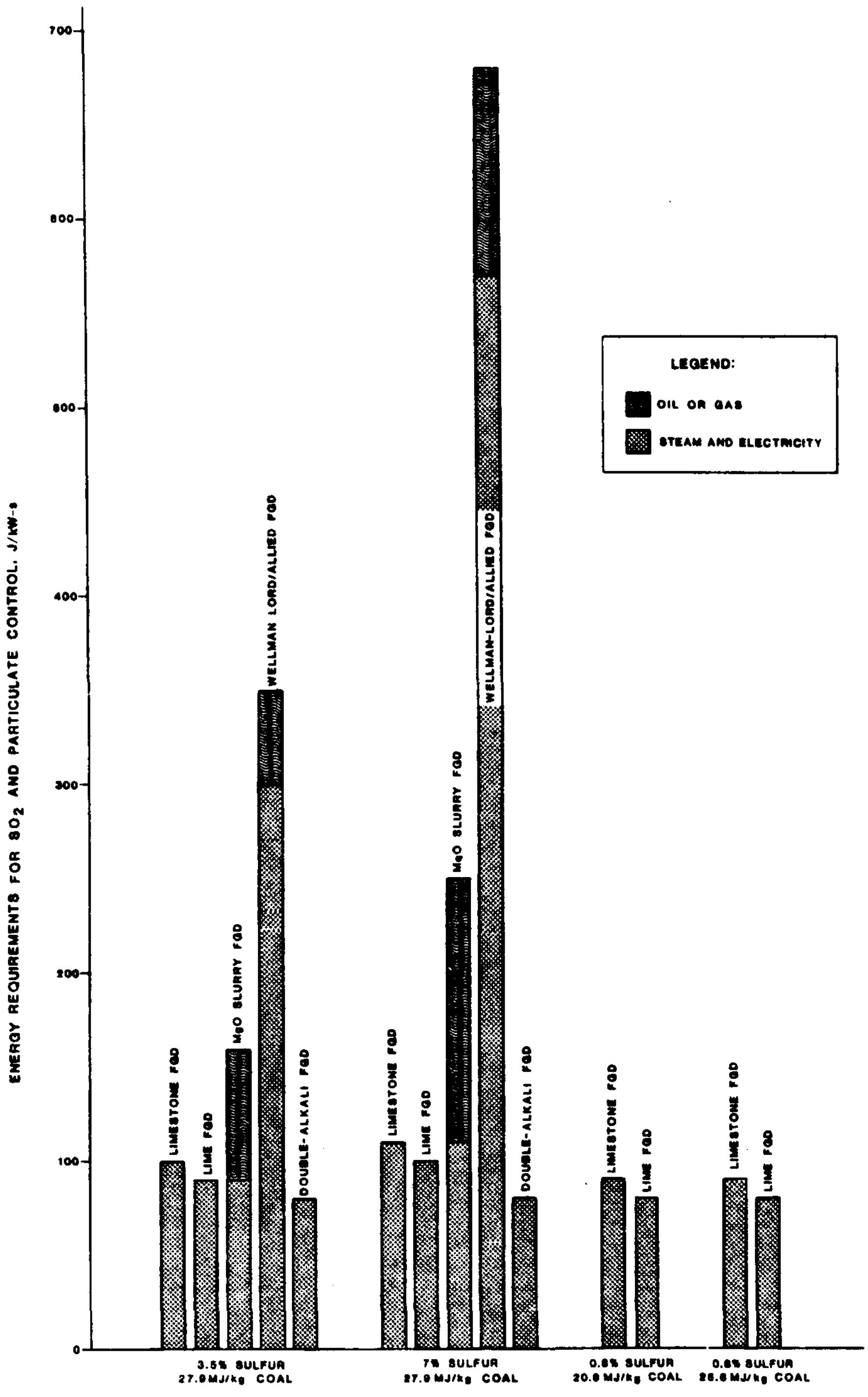

Figure 2. Energy penalties for SO_2 and particulate control - 90% SO_2 removal control level, 500 MW plant.

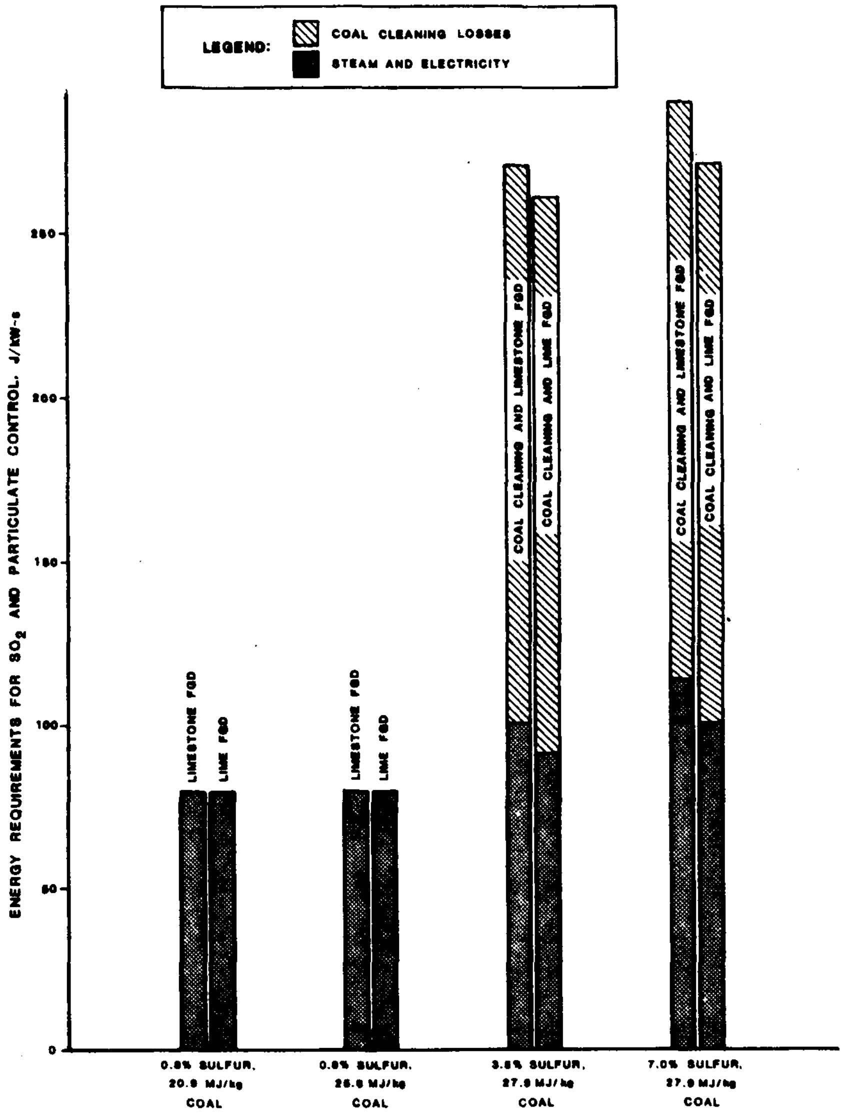

Figure 3. Energy requirements for SO_2 and particulate control - 0.22 g/SO_2/MJ control level, 500 MW plant.

control methods have the same relative variations for the more stringent standards as those for meeting the existing standard. Table 5 summarizes the energy requirements shown in Figures 1 through 3 for combusting a 3.5 percent sulfur coal.

TABLE 5. ENERGY PENALTIES ASSOCIATED WITH DIFFERENT METHODS OF CONTROLLING SO_2 EMISSIONS - 500 MW PLANT, 3.5% SULFUR COAL

SO_2 Control Process	Energy Penalty (% Energy Input To Equivalent Uncontrolled Power Plant)		
	Level of SO_2 Control		
	0.52g SO_2/MJ (NSPS)	90% Removal	0.22g SO_2/MJ
Nonregenerable FGD			
Limestone	3.4	3.8	NE
Lime	3.0	3.4	NE
Double-Alkali	3.0	3.0	NE
Regenerable FGD			
Magnesia Slurry	5.3	6.1	NE
Wellman-Lord/Allied	11.7	13.2	NE
Coal Cleaning Plus Lime/Limestone FGD	9.8	NE	9.8/10.2

NE = Not Examined

3.3 Comparison by SO_2 Control Level

Figure 4 shows how energy penalties depend on the level of SO_2 control. Two levels of control are shown, the existing standard and 90 percent SO_2 removal. Ninety percent removal is a more stringent level of control than the existing standard. Figure 4 shows that for most control methods the energy penalty for achieving 90 percent removal is about 10-15 percent higher than that required to meet the existing NSPS.

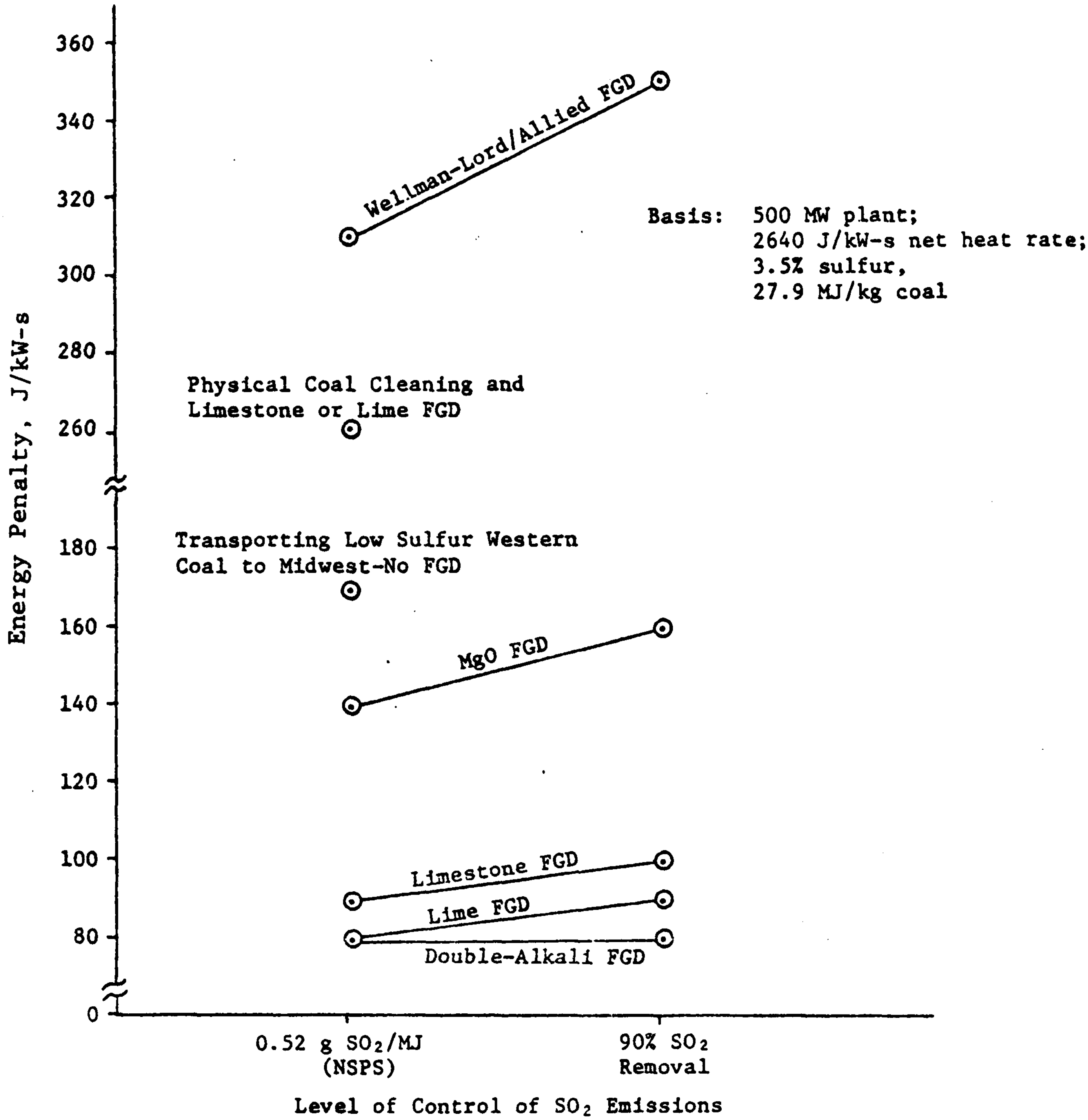

Figure 4. Energy penalties for SO_2 control - summary of effects of SO_2 control level.

The results of the study also show that for combustion of low sulfur western coal, 90 percent SO_2 removal requires up to 10 percent more energy than controlling emissions to 0.22 g SO_2/MJ (0.5 lb $SO_2/10^6$ Btu) of heat input. For low sulfur coals, 0.22 g SO_2/MJ is more stringent than the existing NSPS but less stringent than 90 percent removal.

For a "bare bones" SO_2 control system, the energy required for flue gas reheat and particulate/chloride removal is excluded from the limestone and lime systems. This reduces the energy requirements of these systems by 50 to 60 percent. For the double-alkali, magnesia slurry and Wellman-Lord/Allied processes, the particulate/chloride removal operation is required to prevent buildup of chlorides in the SO_2 scrubbing liquor. However, excluding flue gas reheat requirements would reduce the energy required by the MgO system by 15 to 25 percent, the W-L/A by about 10 percent and the double-alkali by about 50 percent.

3.4 Energy Penalty Projections

The energy penalties associated with SO_2 controls were compared with projected total U.S. energy consumption for 1987 and 1997. Depending on control level, method of control, and sulfur content of coal, the energy required to control SO_2 emissions from new coal-fired power plants installed in 1983 through 1987 will be from 0.1 to 0.4 percent of total energy consumption in 1987. For the new capacity installed in 1983 through 1997, the energy penalty ranges from 0.4 to 1.7 percent of projected U.S. energy consumption in 1997. These ranges are based on combusting 0.8 to 3.5 percent sulfur coal and controlling SO_2 emission to the existing NSPS or effecting 90 percent SO_2 removal. Assuming the majority of future SO_2 controls are limestone or lime FGD systems, as is presently true, estimates for 1987 and 1997 would be 0.1 percent and 0.4 percent, respectively.

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16. ABSTRACT

The report is an executive summary of the main report (EPA-450/3-77-050a). The main report is an analysis of the energy required by various methods of reducing sulfur dioxide emissions from coal-fired boilers. The energy required for limestone, lime, double alkali, magnesium slurry and Wellman-Lord/Allied flue gas scrubbing systems is presented. The variation of energy requirements with coal sulfur content, emission level achieved and plant size is presented. The energy required to transport low sulfur coal to the mid-west or to physically clean sulfur from the coal is presented also.

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