

## CHAPTER IV

### RESULTS AND DISCUSSION

The results presented here were obtained at the condition of 0.2 grams catalyst, and the feed amount of NO and NH<sub>3</sub> at 0.115 volume% each. The factors which affected the conversion of NO in the present studies are reaction temperature, space velocity, the presence of O<sub>2</sub> (3.45 volume%) in the feed, and the composition of catalysts.

#### 4.1 Effect of reaction temperature

The temperature effect on the conversion of NO is shown in Figure 4.1-4.6. The result indicates that the conversion of NO will increase when the temperature rises from 100 °C to 300 °C. This result conforms to the basic thermodynamics principle which indicates that the reaction tends to favourably occur when the temperature rises (the negative values of  $(\Delta G_R^0)_T$  of the first and the second reaction in Table 2.1 increase as the rising of temperature). Conversely, as temperature reaches 400 °C the conversion of NO decreases which does not follow the basic thermodynamics principle mentioned above. It may result from the combustion of NH<sub>3</sub> which the  $(\Delta G_R^0)_T$  of NH<sub>3</sub> combustion (in Table 2.1) indicates that it is favourable. The NH<sub>3</sub> combustion will produce NO or N<sub>2</sub> and a little

amount of  $N_2O$ . Odenbran et al. (1985) reported that NO readily occurred from the combustion of  $NH_3$ . Besides, Cavani et al. (1980) found  $N_2$  and  $N_2O$  occurred from the same reaction. The combustion of  $NH_3$  with  $O_2$  is expressed as the ninth, the tenth, and the eleventh reaction in Table 2.1. In the absence of  $O_2$ ,  $N_2O$  may occur from the side reaction of  $NO-NH_3$  expressed as the twelfth reaction in Table 2.1. However, the amount of  $N_2O$  may be too low to be detected by gas chromatography. Niiyama et al. (1980) and many researchers have found the similar temperature effect to this work even with different kinds of catalysts.

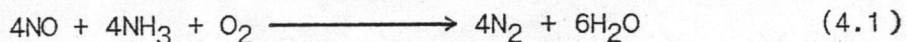
#### 4.2 Effect of space velocity

The effect of space velocity are shown in Figure 4.7-4.12. The result indicates that the NO conversion will reduce when the space velocity increases from 18820-75280  $hr^{-1}$  for all catalysts with and without  $O_2$  in the reaction. This can be explained by the reason that the increasing of space velocity reduces the contact time at the active sites and leads to the incompleteness of NO reduction.

#### 4.3 Effect of addition $O_2$ into $NO-NH_3$ reaction system

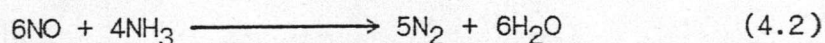
This effect is shown in Figure 4.1-4.6. The result points out that, in the presence of  $O_2$ , more percentage of NO conversion was obtained than that in the absence of  $O_2$  for all catalysts. Addition of

3.45 volume% O<sub>2</sub> increases approximately one fold the NO conversion, these results are similar to the work of Inomata et al.(1980). In the presence of O<sub>2</sub>, Table C7-C12 show that the mole ratio of NO:NH<sub>3</sub> is approximately 1:1. This reveals that the reaction between NO and NH<sub>3</sub> may occur as the following reaction

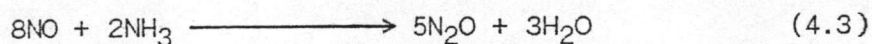


However, the measuring N<sub>2</sub> amount is slightly higher than 100% in comparison with N<sub>2</sub> calculated from the actual conversion of NO of reaction (4.1). This may be due to the oxidation of NH<sub>3</sub> to N<sub>2</sub> and N<sub>2</sub>O as explained in section 4.1.

In absence of O<sub>2</sub>, Table C1 - C6 show that the mole ratio of NO:NH<sub>3</sub> is about 1:0.892 which is not likely the stoichiometry of NO:NH<sub>3</sub> of 1:0.667 in reaction (4.2).



And the percentage of measuring N<sub>2</sub> is approximately 87 % in comparison with N<sub>2</sub> calculated from the actual conversion of NO of reaction (4.2). The disappearance of 13% N<sub>2</sub> and mismatch of NO:NH<sub>3</sub> mole ratio may be the result from the side reactions such as reaction (4.3).

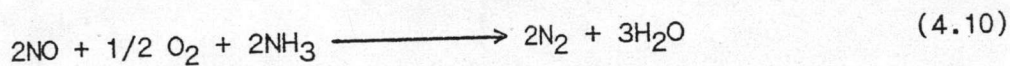
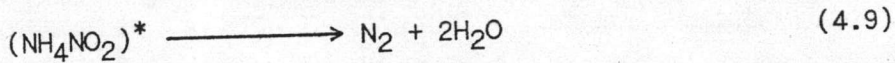
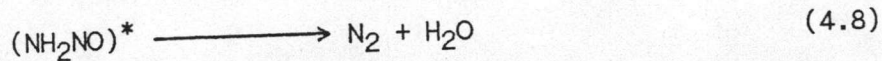
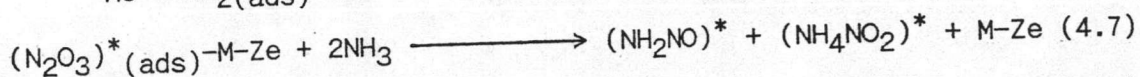
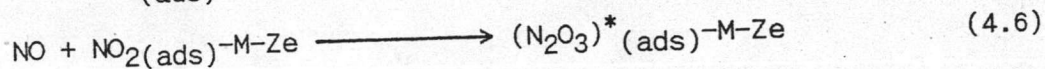
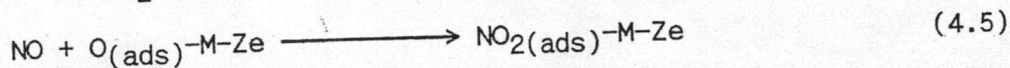
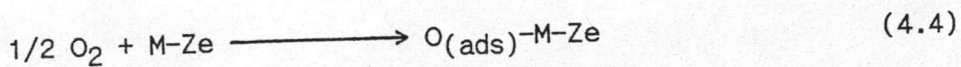




This reaction is favourable confirmed by the value of  $(\Delta G_R^0)_T$  of the twelfth reaction in Table 2.1. However, very small minute amount of  $N_2O$  may be produced from the  $NO-NH_3$  reaction either in the presence or absence of  $O_2$ .

From the experimental results, the participation of  $O_2$  in the reaction of  $NO-NH_3$  has two different pathways which depend on each type of used catalysts in this work. In case of cation-exchanged zeolite,  $O_2$  has a role in the step of  $NO$  oxidation. Firstly,  $O_2$  adsorbs on surface of zeolite at cation sites called oxygen surface. Subsequently,  $NO_2$  species are produced by the reaction between  $NO$  (from the feed) and oxygen surface. Considering the characteristic of electron transfer in the reaction of  $NO-NH_3-O_2$  system which is expressed in reaction 2.12-2.14, these sets of reactions indicate that electron receivers are  $NO$  and  $O_2$ , by the fact that the electron affinity of  $NO_2$  is much higher than that of  $O_2$  (see Table 4.1). This means that it can attract electron from  $NH_3$  easier than  $O_2$ . Therefore, the oxidation of  $NO$  by  $O_2$  is the important step although the values of  $(\Delta G_R^0)_T$  of  $NO$  oxidation, the third reaction in Table 2.1, indicates that this reaction is unfavourable. This reaction is promoted by cation exchanged zeolite that has high electron field and transition metal cations have the ability to change valence state easily, and can therefore function as an intermediate storage for electrons that are needed in the reaction. So, these are sufficiently reasonable to propose a general mechanism for the reduction of  $NO$  by  $NH_3$  as expressed in the following set of reactions;





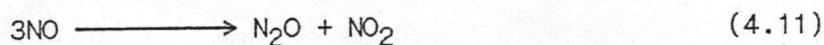
where M-Ze stands for a cation exchanged zeolite, M is cation such as  $\text{Cu}^{2+}$  and  $\text{Pt}^{2+}$ , (ads) denotes an adsorbed species and ( )<sup>\*</sup> is a reaction intermediate.

Table 4.1 Ionization potential energy and Electron affinity for one electron transfer

species	IP (EV)	EA (EV)
NO	9.25	-
NO <sub>2</sub>	9.75	3.91
O <sub>2</sub>	12.06	0.45

From : Brandin et al. "Catalyst reduction of nitrogen oxide on mordenite some aspect on the mechanism" Journal of Catalysis Today, Volume 4,(1989); PP 197.

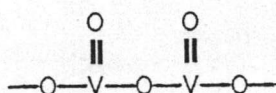
The formation of a  $N_2O_3$ -like intermediate could be a fast step, since it is known that in the gas phase the equilibrium of  $NO-NH_3$  with  $N_2O_3$  is established within microseconds. It seems reasonable to assume that step (4.7)-(4.9) are fairly fast step too. Intermediate  $N_2O_3$  reacts on the catalyst surface either with gas phase ammonia or with ammonia bound to Lewis and Bronsted acid centers. Farber and Harris confirmed  $NH_2NO$  intermediate formation, by mass spectrometry, with a lifetime of about 100 microseconds. The work of Farber and Harris is referred by Luck and Roiron (1989). Lastly, lifetime of intermediate  $NH_4NO_2$  is extremely short, at current temperature involved in  $NO$  reduction. In the absence  $O_2$  in feed gaseous reactant, the formation of  $NO_2$  is established by disproportionation of  $NO$  as described by the reaction below



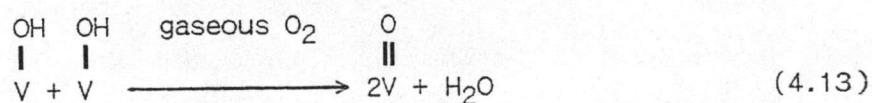
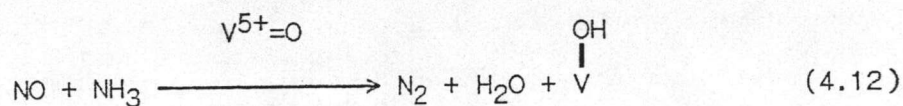
However, the amount of established  $NO_2$  from reaction (4.11) may be less than in the presence of  $O_2$  by the reason that the capability to draw electron of three molecules of  $NO$  is equal. Therefore, the  $NO$  conversion in the presence of  $O_2$  is higher than in the absence of  $O_2$ . Further details of this mechanism, however, should be clarified by IR or other methods.

In case of vanadium oxide catalyst, the participation of  $O_2$  in the reaction of  $NO-NH_3$  is directly supplied from the lattice oxygen of the catalyst. It seems reasonable to explain that the quantity of lattice oxygen of vanadium oxide catalyst is much more than that of

adsorbed oxygen and the lattice oxygen of catalyst can diffuse easily from bulk to surface. This explanation is confirmed by the work of Inomata et al.(1980). Consider the molecular structure of vanadium oxide as  $V_2O_5$  below,



the structure indicates that the arrangement of oxygen atoms are set as the balanced state which conforms to octave rule. So,  $O_2$  from gaseous reactants hardly attracts on surface of  $V_2O_5$  by the method of adsorption at  $V^{5+}=O$  species. For the reaction of  $NO-NH_3$  to take place,  $NH_3$  is the first species which adsorbs at  $V^{5+}=O$  species by hydrogen bonding. The adsorption of  $NH_3$  is easier than the adsorption between  $V^{5+}=O$  and  $O_2$  because  $V^{5+}=O$  can polarize oxygen atom as the negative polar and  $NH_3$  can polarize hydrogen atom as the positive polar whereas gaseous  $O_2$  can not self-polarize. The opposite polarity of the two species can result in weak bonding. Thus, it seems reasonable to suggest that the active site of  $V_2O_5$  as catalyst for  $NO-NH_3$  reaction is  $V^{5+}=O$  species. Subsequently, adsorption of  $NO$  on the adsorbed  $NH_3$  occurs through the hydrogen bonding between oxygen atom of  $NO$  and two hydrogen atoms of adsorbed  $NH_3$ . The participation of  $O_2$  in the reaction can be expressed by the set of reactions below.





From reaction (4.13), gaseous  $O_2$  from the feed is used to convert the reduction site to an oxidation site. In the presence of  $O_2$ , the  $V^{5+}=O$  species on the surface is reproduced by reaction (4.13) with the expense of bulk  $V^{5+}=O$  species, followed by the formation of  $V^{4+}$  ion in bulk. As a consequence, the quantity of  $V^{5+}=O$  should decrease completely after the long duration of NO-NH<sub>3</sub> reaction in the absence of gaseous  $O_2$  and the conversion of NO is lower than in the presence of gaseous  $O_2$ . This mechanism has been proposed by Miyamoto et al.(1982) and the scheme is shown in Figure 2.2. In the present study, TiO<sub>2</sub> is used as the supporting material. TiO<sub>2</sub> is useful for V<sub>2</sub>O<sub>5</sub> catalyst as the storage of lattice oxygens which are used in NO-NH<sub>3</sub> reaction. So, V<sub>2</sub>O<sub>5</sub>-TiO<sub>2</sub> should be better than pure V<sub>2</sub>O<sub>5</sub>.

#### 4.4 Influence of catalyst compositions

In the present study, catalysts can be classified to two main types. The first type of catalyst is cation-exchanged zeolite which is composed of Pt-HY and Cu-Pt-HY. The other is vanadium pentoxide with and without TiO<sub>2</sub> as the supporting material. In case of cation-exchanged zeolite, Figure 4.13-4.20 show that Cu-Pt-HY gave higher activity than Pt-HY for all conditions. The enhanced activity on the conversion of NO can be explained by the fact that Cu was able to adsorb  $O_2$  especially in a very dilute concentration since  $O_2$  is necessary to oxidize NO to NO<sub>2</sub> species. This reason is confirmed by the suggestion of Niiyama et al.(1980) which stated that catalyst of low  $O_2$ -adsorptive properties have no ability to adsorb NO as NO<sub>2</sub> species. Therefore, loading of Cu into Pt-HY increases an active site for  $O_2$  adsorption.

Moreover, at high temperature and in the presence of  $O_2$ ,  $Pt^{2+}$  is more likely to reduce itself to pure metal than  $Cu^{2+}$ . This behaviour is confirmed by the standard redox potential energy of the metal as shown in Table 4.2. So, the activity of Pt-HY catalyst is maintained by Cu.

Table 4.2 The standard redox potential energy of Cu and Pt at 25 °C

couple	E/V
$Cu^{2+} + e^- \longrightarrow Cu^+$	0.16
$Cu^{2+} + 2e^- \longrightarrow Cu$	0.34
$Cu^+ + e^- \longrightarrow Cu$	0.52
$Pt^{2+} + 2e^- \longrightarrow Pt$	1.20

From: M.S. Antelman. "The Encyclopedia of Chemical Electrode Potentials", Plenum, New York, 1982.

In case of  $V_2O_5-TiO_2$ , Figure 4.13-4.20 indicate that NO conversion increases with higher content of  $V_2O_5$  on  $TiO_2$  for all conditions. This result can be explained by the fact that the active site ( $V^{5+}=O$  species) increases with increasing of  $V_2O_5$  content. However, pure  $V_2O_5$  gives the lowest NO conversion in comparison with the other  $V_2O_5-TiO_2$  catalysts in the absence of  $O_2$ . This may be due from the impregnation of  $V_2O_5$  on  $TiO_2$  causing the structure to be defective and this will result in the easy transfers of electron at the catalyst surface. This effect enhances NO conversion to occur

higher than that in case of pure crystalline  $V_2O_5$ . In the presence of  $O_2$ , pure  $V_2O_5$  gives the higher NO conversion than  $V_2O_5-TiO_2$  as 8.54 wt% of  $V_2O_5$ . This result may be due from the amount of active sites ( $V^{5+}=O$  species) of pure  $V_2O_5$  having more than  $V_2O_5-TiO_2$  as 8.54 wt% content of  $V_2O_5$ . Comparatively, the order of NO conversion affected by various catalysts can be arranged like this 25.61 wt%  $V_2O_5 > 15.0$  wt%  $V_2O_5 \geq Cu-Pt-HY > 8.54$  wt%  $V_2O_5 \geq$  pure  $V_2O_5 > Pt-HY$ .



Table 4.3 Percentage of apparent  $N_2$  in comparison with theory;Condition A :  $NO(0.119\%)-NH_3(0.119\%)-O_2(\text{free})$ Condition B :  $NO(0.115\%)-NH_3(0.115\%)-O_2(3.45\%)$ 

Catalyst : Pt-HY (Pt = 5.0 wt%)

reaction temperature, °C	space velocity, $hr^{-1}$	percentage of $N_2$	
		condition A	condition B
100	18820	83.20	104.94
	37640	82.23	106.70
	56460	81.22	103.27
	75280	78.76	102.16
200	18820	86.48	106.71
	37640	85.98	105.69
	56460	85.41	105.02
	75280	84.04	95.97
300	18820	87.33	107.24
	37640	87.05	106.36
	56460	86.48	106.05
	75280	85.66	103.38
400	18820	87.10	107.10
	37640	86.67	106.33
	56460	86.05	105.89
	75280	84.37	103.14

Table 4.4 Percentage of apparent  $N_2$  in comparison with theory;Condition A :  $NO(0.119\%) - NH_3(0.119\%) - O_2(\text{free})$ Condition B :  $NO(0.115\%) - NH_3(0.115\%) - O_2(3.45\%)$ 

Catalyst : Cu-Pt-HY (Cu = 4.9 wt%, Pt = 5.0 wt%)

reaction temperature, °C	space velocity, $hr^{-1}$	percentage of $N_2$	
		condition A	condition B
100	18820	86.19	106.79
	37640	85.66	105.51
	56460	84.37	104.86
	75280	83.82	101.76
200	18820	88.38	115.23
	37640	88.04	107.30
	56460	87.09	104.45
	75280	86.81	104.43
300	18820	89.16	108.52
	37640	88.29	107.69
	56460	87.99	105.11
	75280	87.69	105.10
400	18820	88.80	108.30
	37640	87.89	107.53
	56460	87.69	104.86
	75280	87.29	104.80

Table 4.5 Percentage of apparent  $N_2$  in comparison with theory;Condition A :  $NO(0.119\%)-NH_3(0.119\%)-O_2(\text{free})$ Condition B :  $NO(0.115\%)-NH_3(0.115\%)-O_2(3.45\%)$ Catalyst :  $V_2O_5-TiO_2$  ( $V_2O_5 = 8.54 \text{ wt\%}$ )

reaction temperature, °C	space velocity, $hr^{-1}$	percentage of $N_2$	
		condition A	condition B
100	18820	87.26	100.49
	37640	86.68	102.64
	56460	85.83	103.35
	75280	84.38	102.98
200	18820	88.56	102.20
	37640	88.11	104.04
	56460	88.06	104.73
	75280	87.16	104.75
300	18820	88.95	102.20
	37640	88.48	104.31
	56460	88.27	104.98
	75280	88.33	105.15
400	18820	88.76	101.80
	37640	88.29	103.75
	56460	88.09	104.59
	75280	87.65	104.80



Table 4.6 Percentage of apparent  $N_2$  in comparison with theory;Condition A :  $NO(0.119\%)-NH_3(0.119\%)-O_2(\text{free})$ Condition B :  $NO(0.115\%)-NH_3(0.115\%)-O_2(3.45\%)$ Catalyst :  $V_2O_5-TiO_2$  ( $V_2O_5 = 15.0 \text{ wt\%}$ )

reaction temperature, $^{\circ}C$	space velocity, $hr^{-1}$	percentage of $N_2$	
		condition A	condition B
100	18820	87.05	101.02
	37640	86.67	103.16
	56460	86.19	103.59
	75280	79.61	103.37
200	18820	88.43	102.87
	37640	87.99	104.95
	56460	87.69	105.35
	75280	86.93	105.42
300	18820	89.09	103.35
	37640	88.35	105.33
	56460	88.21	105.74
	75280	87.79	105.58
400	18820	88.79	103.18
	37640	87.90	105.14
	56460	87.89	105.44
	75280	87.33	106.04

Table 4.7 Percentage of apparent  $N_2$  in comparison with theory;Condition A :  $NO(0.119\%)-NH_3(0.119\%)-O_2(\text{free})$ Condition B :  $NO(0.115\%)-NH_3(0.115\%)-O_2(3.45\%)$ Catalyst :  $V_2O_5-TiO_2$  ( $V_2O_5 = 25.61 \text{ wt\%}$ )

reaction temperature, $^{\circ}C$	space velocity, $hr^{-1}$	percentage of $N_2$	
		condition A	condition B
100	18820	86.86	101.15
	37640	86.51	103.50
	56460	86.33	104.15
	75280	84.96	103.94
200	18820	88.64	103.01
	37640	88.38	104.79
	56460	87.40	105.44
	75280	87.09	105.32
300	18820	89.30	103.60
	37640	88.80	105.33
	56460	88.10	105.90
	75280	87.33	105.88
400	18820	89.09	103.36
	37640	88.64	105.21
	56460	88.06	105.73
	75280	87.25	105.70

Table 4.8 Percentage of apparent  $N_2$  in comparison with theory;Condition A :  $NO(0.119\%)-NH_3(0.119\%)-O_2(\text{free})$ Condition B :  $NO(0.115\%)-NH_3(0.115\%)-O_2(3.45\%)$ Catalyst : pure  $V_2O_5$ 

reaction temperature, $^{\circ}C$	space velocity, $hr^{-1}$	percentage of $N_2$	
		condition A	condition B
100	18820	86.75	100.94
	37640	85.05	103.01
	56460	84.26	103.28
	75280	87.44	103.52
200	18820	87.21	102.91
	37640	86.02	100.56
	56460	85.61	95.32
	75280	91.19	104.71
300	18820	86.94	103.22
	37640	86.48	104.94
	56460	85.58	105.35
	75280	87.33	105.18
400	18820	87.66	102.87
	37640	85.66	104.85
	56460	84.26	104.85
	75280	83.51	105.85



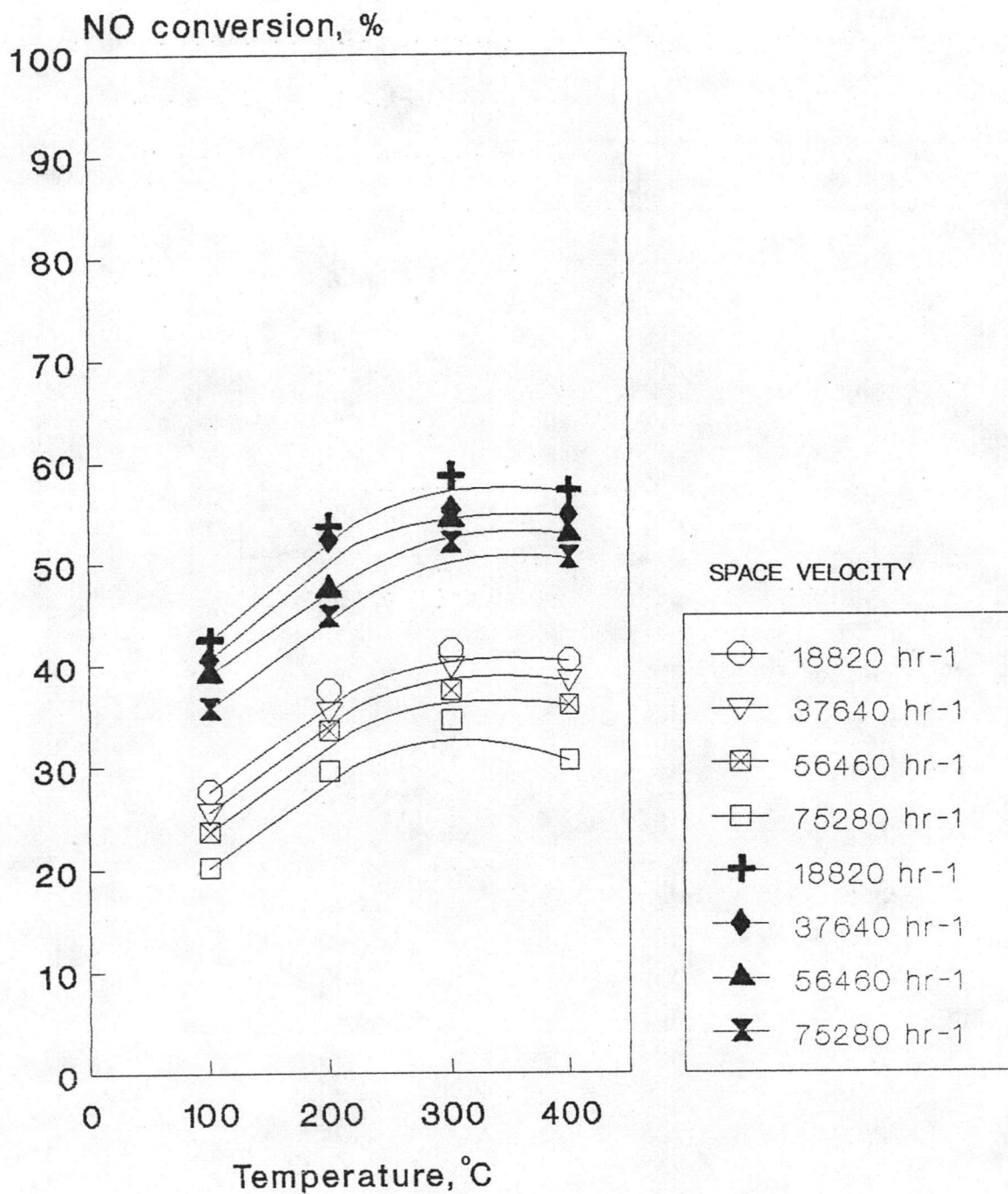


Figure 4.1 NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%) (solid symbols), concentration of NO and NH<sub>3</sub> in the feed: NO = NH<sub>3</sub> 1149 ppm ; Catalyst = Pt-HY

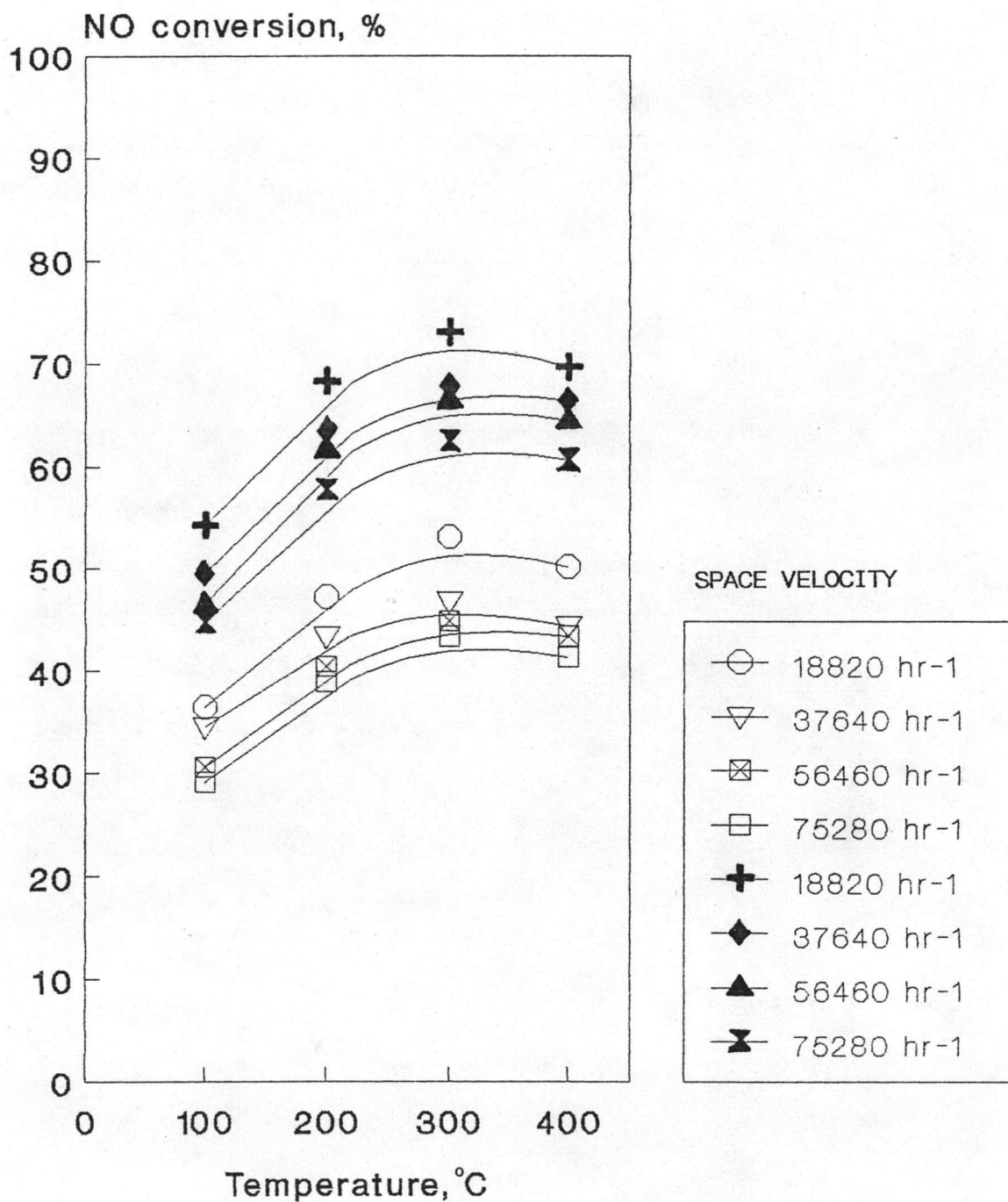


Figure 4.2 NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%) (solid symbols), concentration of NO and NH<sub>3</sub> in the feed: NO = NH<sub>3</sub> 1149 ppm ; Catalyst = Cu-Pt-HY

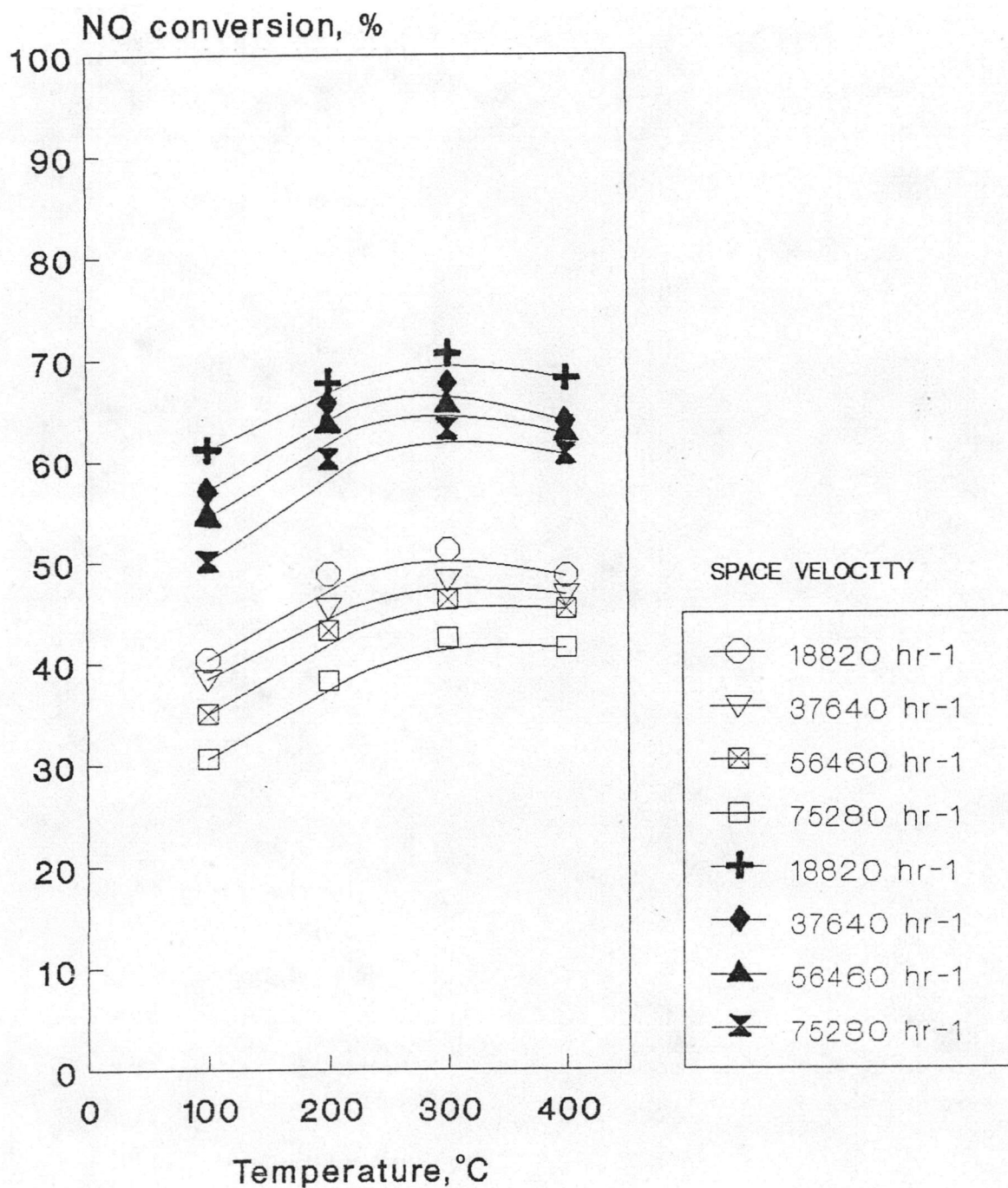


Figure 4.3 NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%) (solid symbols), concentration of NO and NH<sub>3</sub> in the feed: NO = NH<sub>3</sub> 1149 ppm ; Catalyst = V<sub>2</sub>O<sub>5</sub>-TiO<sub>2</sub> No.1



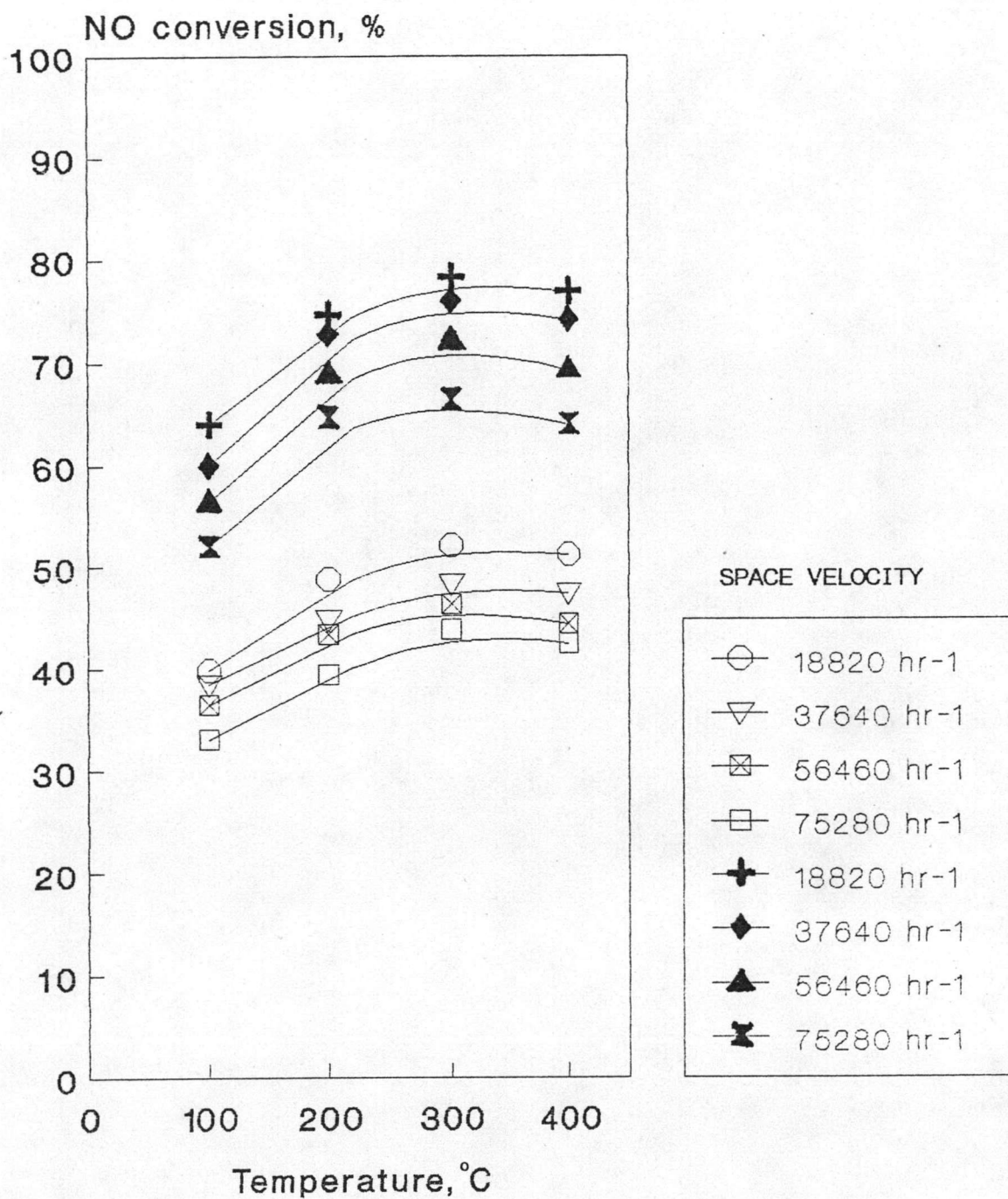


Figure 4.4 NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%) (solid symbols), concentration of NO and NH<sub>3</sub> in the feed: NO = NH<sub>3</sub> 1149 ppm ; Catalyst = V<sub>2</sub>O<sub>5</sub>-TiO<sub>2</sub> No.2

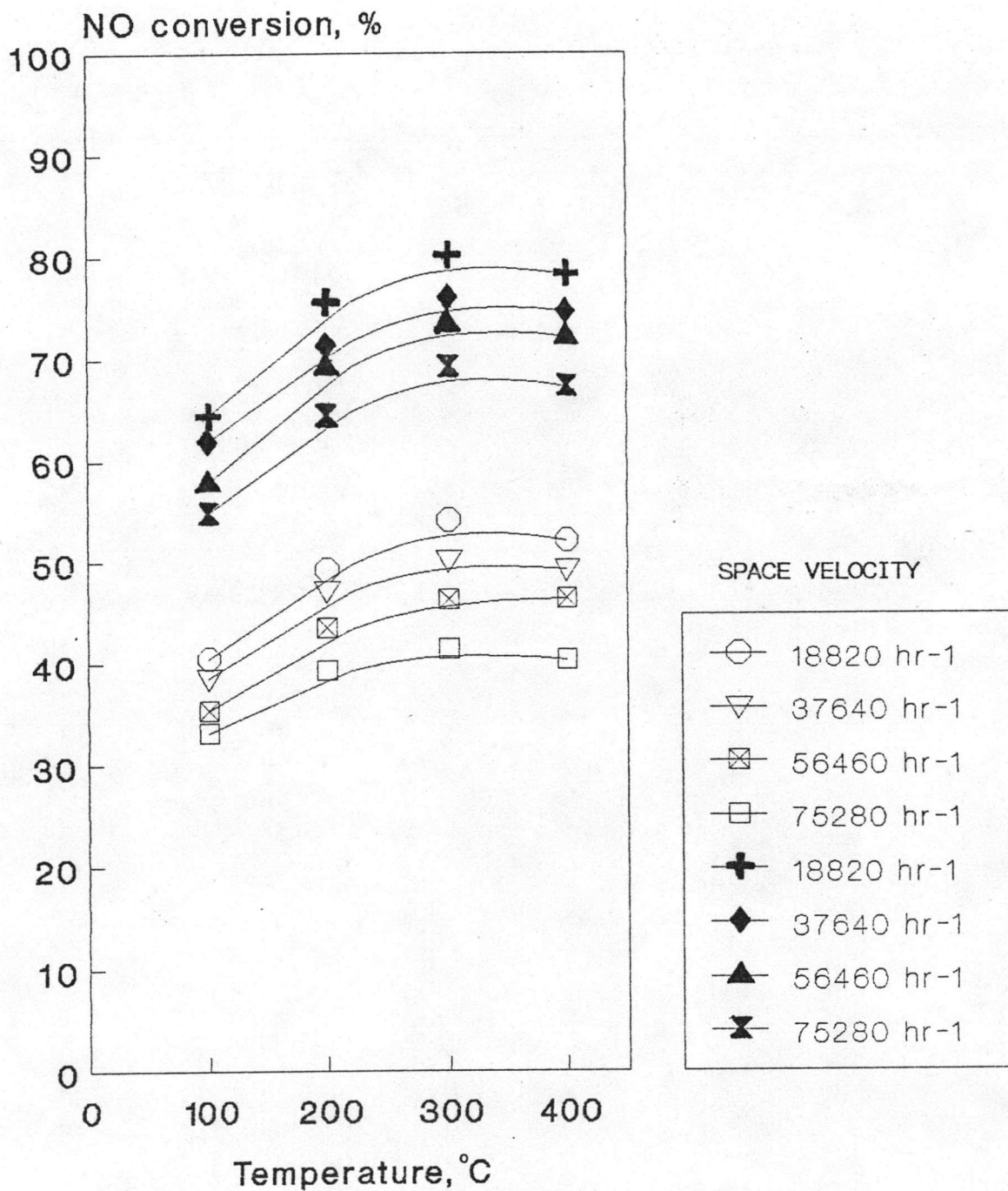


Figure 4.5 NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%) (solid symbols), concentration of NO and NH<sub>3</sub> in the feed: NO = NH<sub>3</sub> 1149 ppm ; Catalyst = V<sub>2</sub>O<sub>5</sub>-TiO<sub>2</sub> No.3

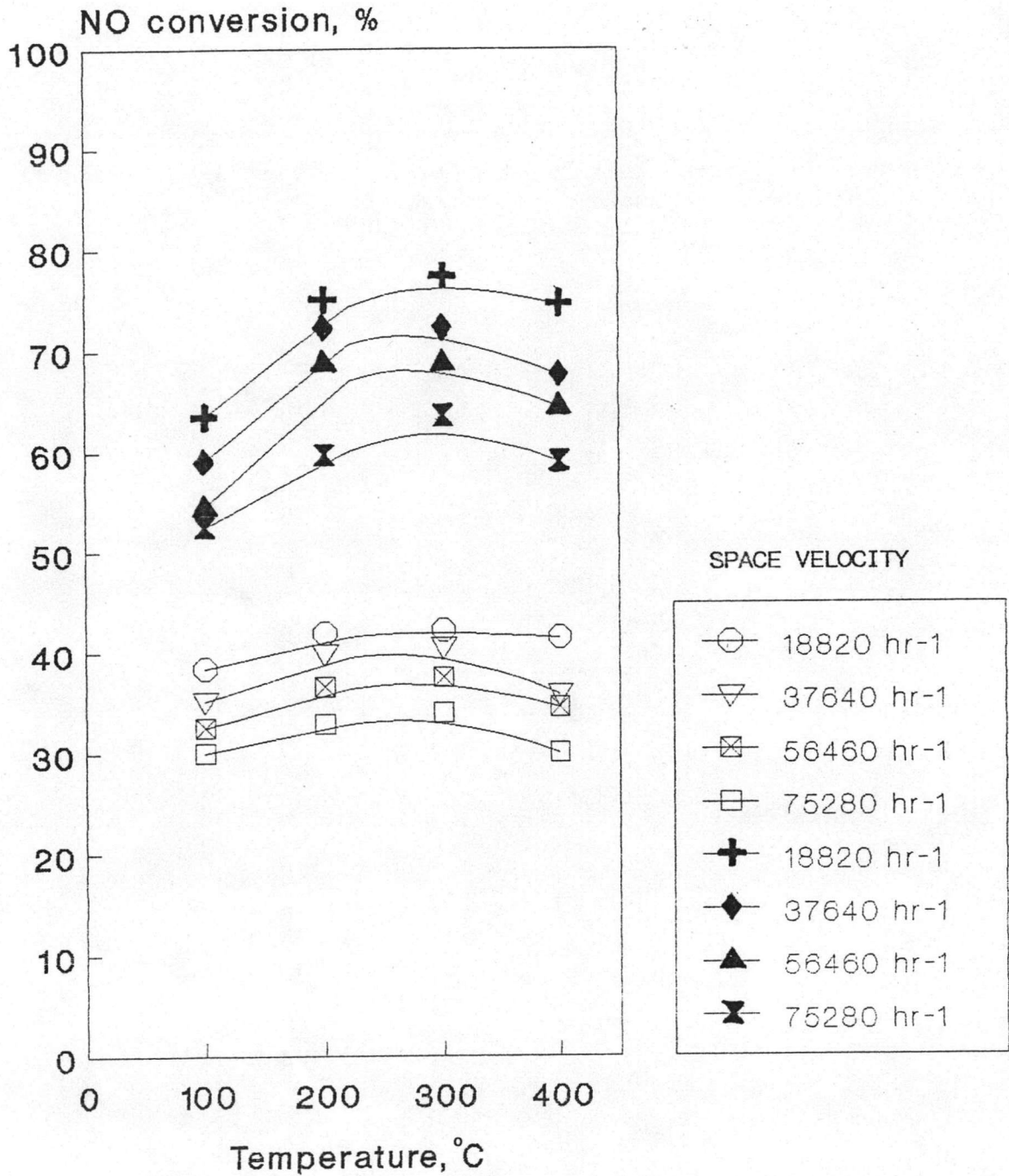


Figure 4.6 NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%) (solid symbols), concentration of NO and NH<sub>3</sub> in the feed: NO = NH<sub>3</sub> 1149 ppm ; Catalyst = V<sub>2</sub>O<sub>5</sub> pure



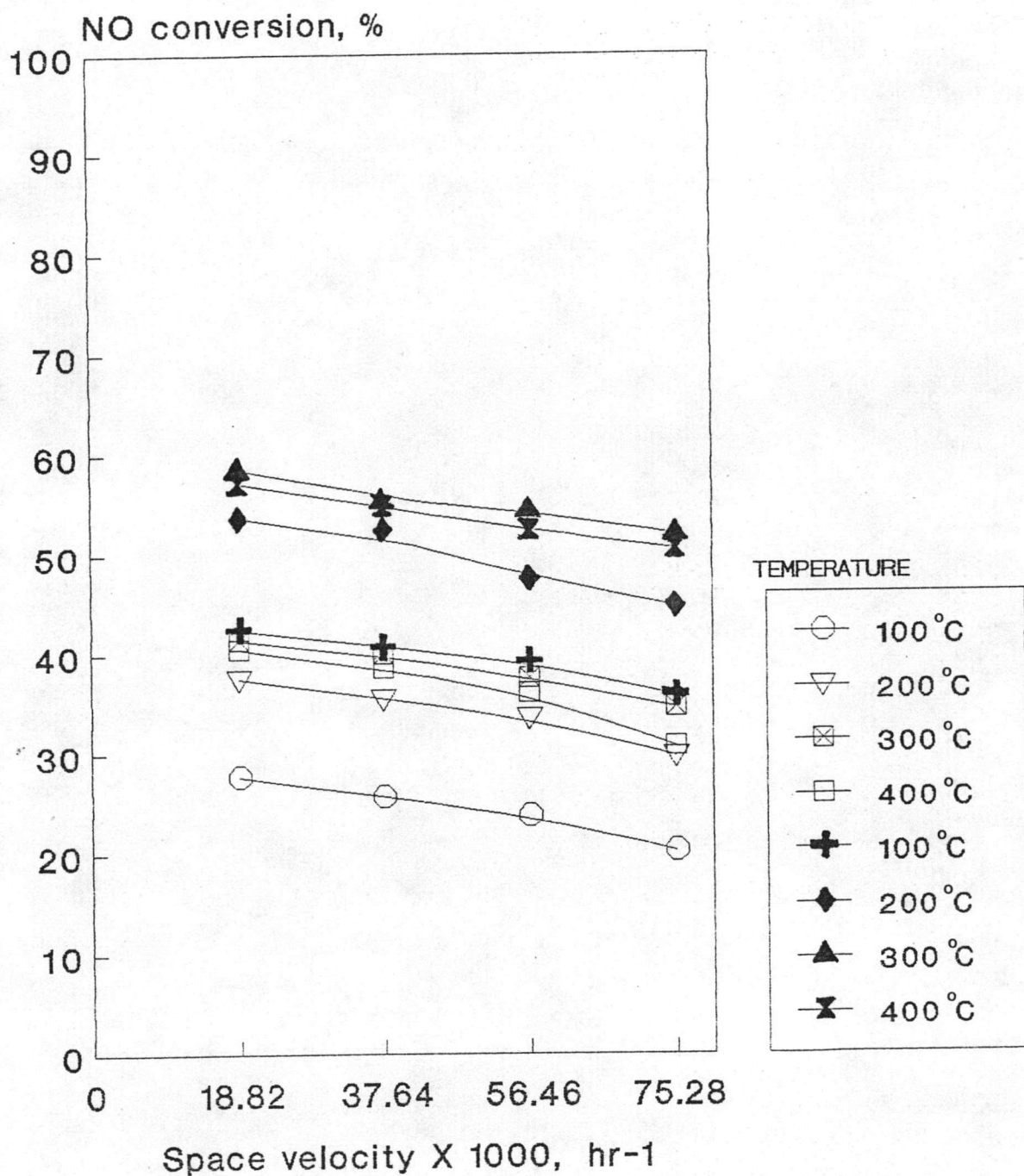


Figure 4.7 Effect of space velocity on NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%)(solid symbols) concentration of NO and NH<sub>3</sub> in the feed: NO = 1149 ppm, NH<sub>3</sub> 1149 ppm ; Catalyst = Pt-HY

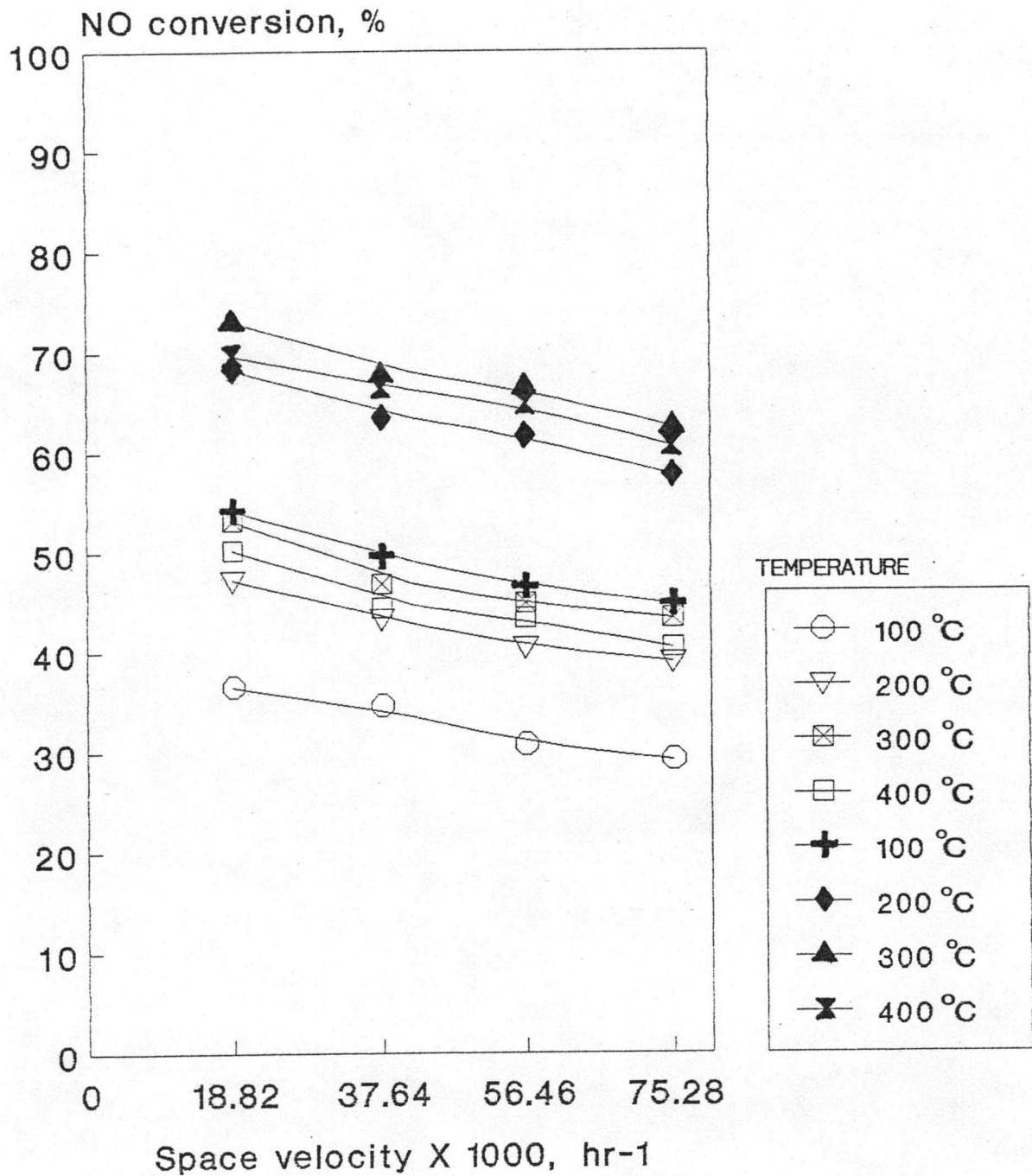


Figure 4.8 Effect of space velocity on NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%)(solid symbols) concentration of NO and NH<sub>3</sub> in the feed: NO = 1149 ppm, NH<sub>3</sub> 1149 ppm ; Catalyst = Cu-Pt-HY

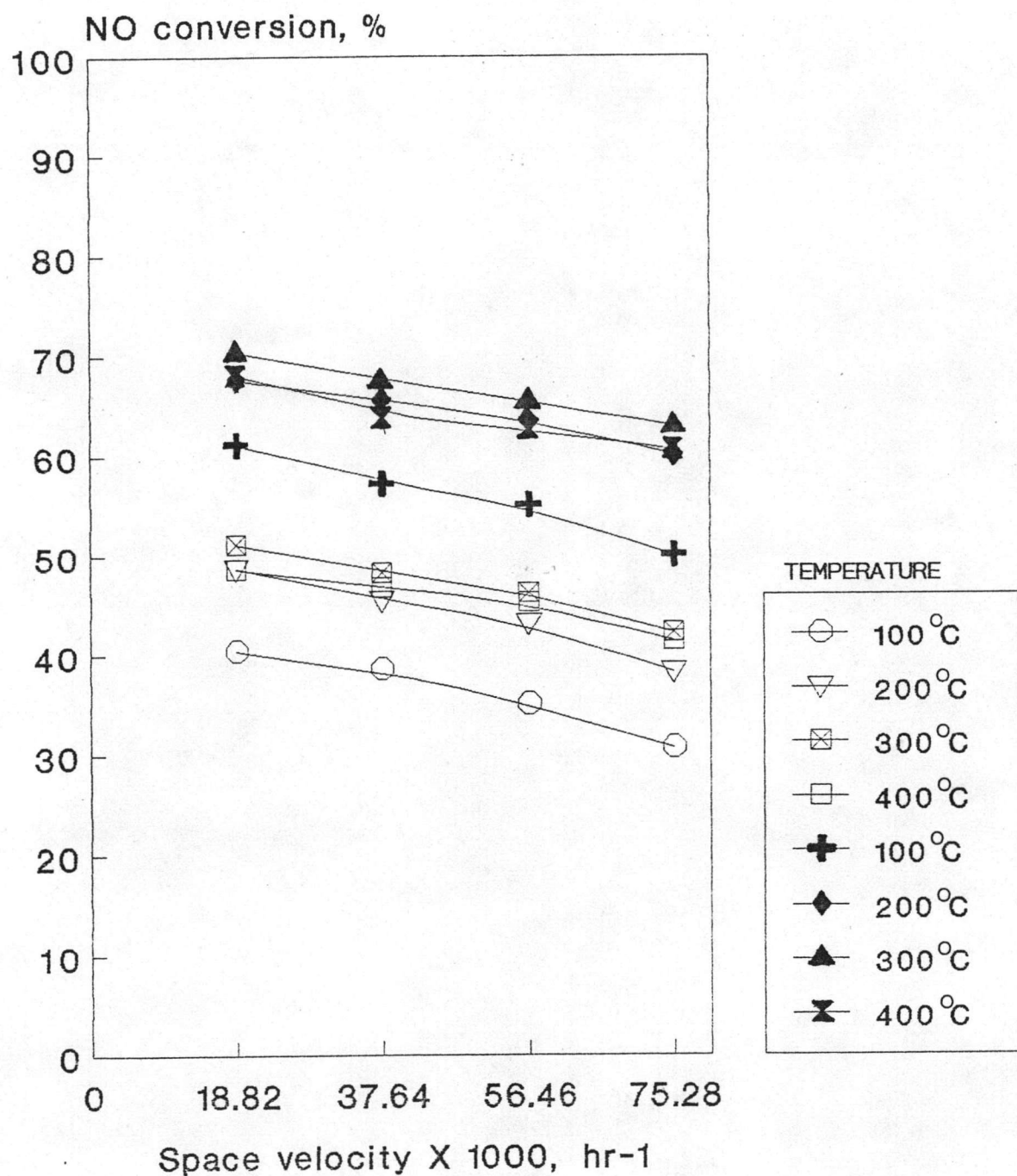


Figure 4.9 Effect of space velocity on NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%) (solid symbols) concentration of NO and NH<sub>3</sub> in the feed: NO = 1149 ppm, NH<sub>3</sub> 1149 ppm ; Catalyst = V<sub>2</sub>O<sub>5</sub>-TiO<sub>2</sub> No.1



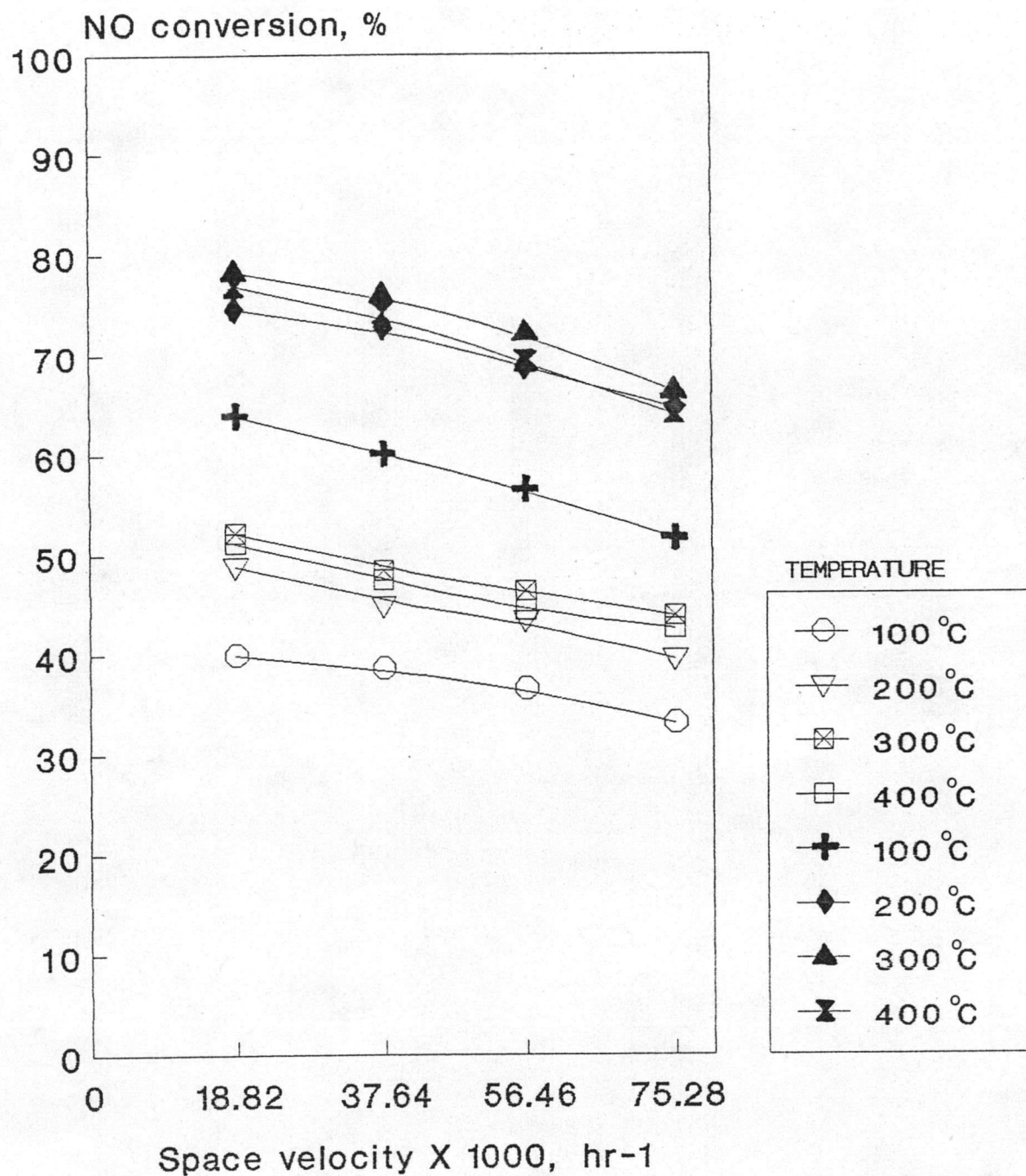


Figure 4.10 Effect of space velocity on NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%)(solid symbols) concentration of NO and NH<sub>3</sub> in the feed: NO = 1149 ppm, NH<sub>3</sub> 1149 ppm ; Catalyst = V<sub>2</sub>O<sub>5</sub>-TiO<sub>2</sub> No.2

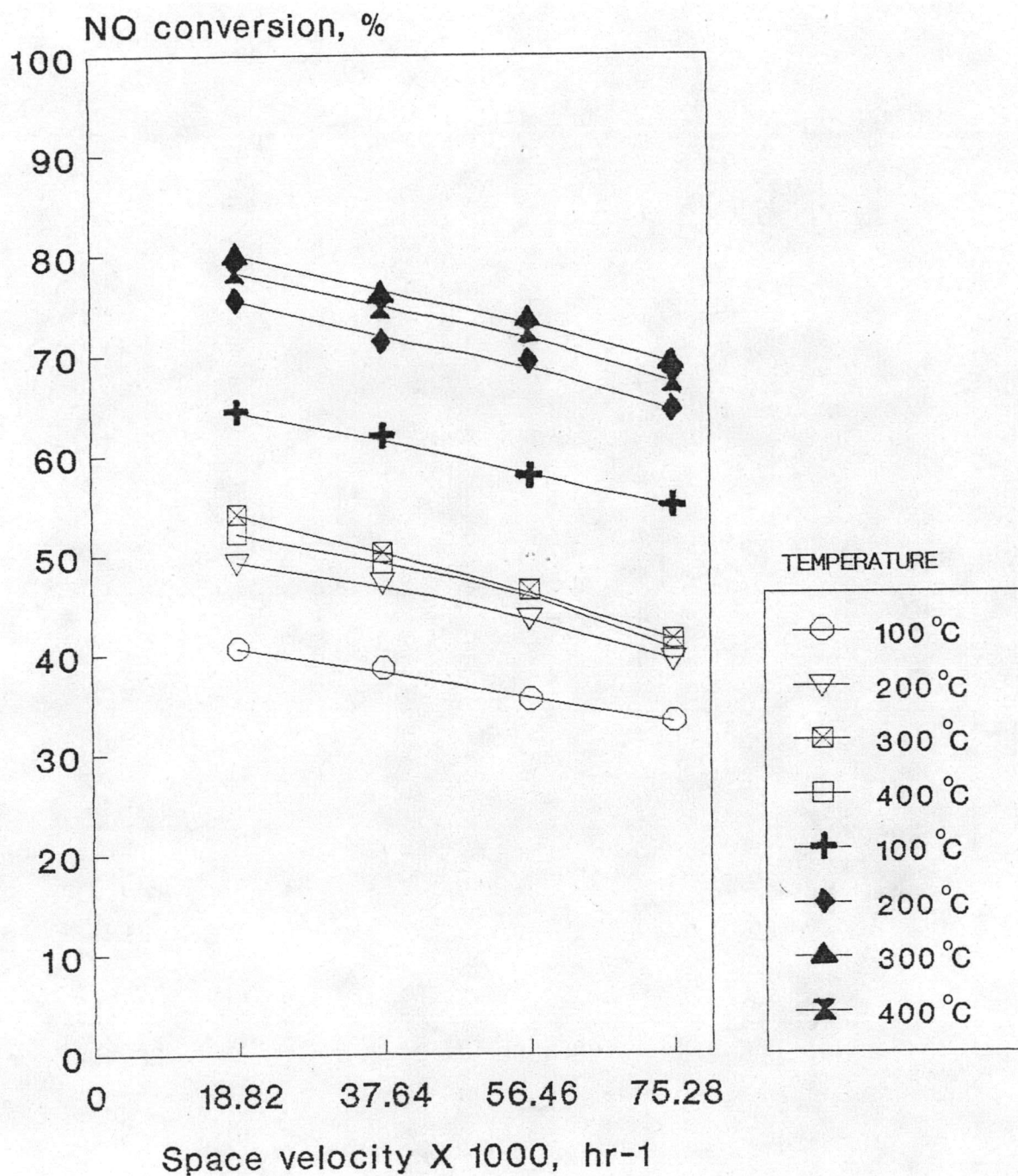


Figure 4.11 Effect of space velocity on NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%)(solid symbols) concentration of NO and NH<sub>3</sub> in the feed: NO = 1149 ppm, NH<sub>3</sub> 1149 ppm ; Catalyst = V<sub>2</sub>O<sub>5</sub>-TiO<sub>2</sub> No.3

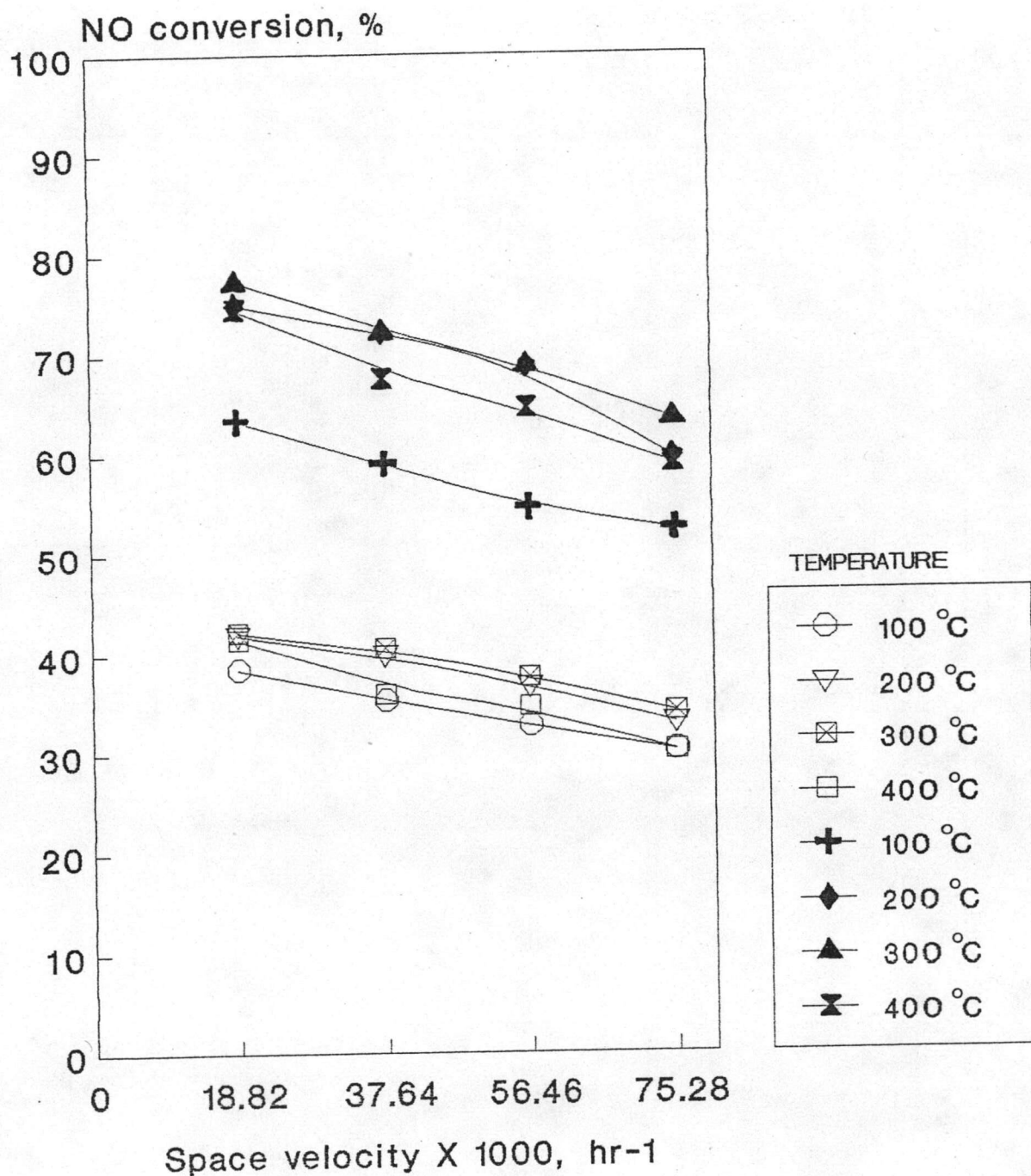


Figure 4.12 Effect of space velocity on NO conversion of NO-NH<sub>3</sub>-O<sub>2</sub> reaction in the absence (open symbols) and the presence of O<sub>2</sub> (3.45%)(solid symbols) concentration of NO and NH<sub>3</sub> in the feed: NO = 1149 ppm, NH<sub>3</sub> 1149 ppm ; Catalyst = V<sub>2</sub>O<sub>5</sub> pure



## SPACE VELOCITY 18820 hr<sup>-1</sup>

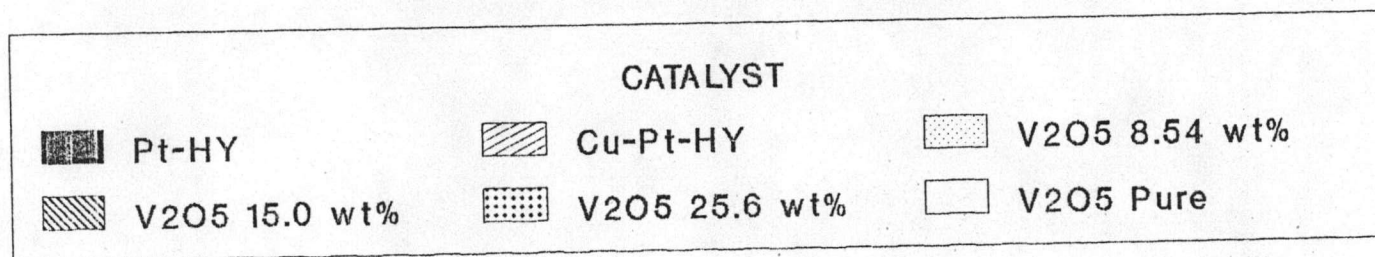
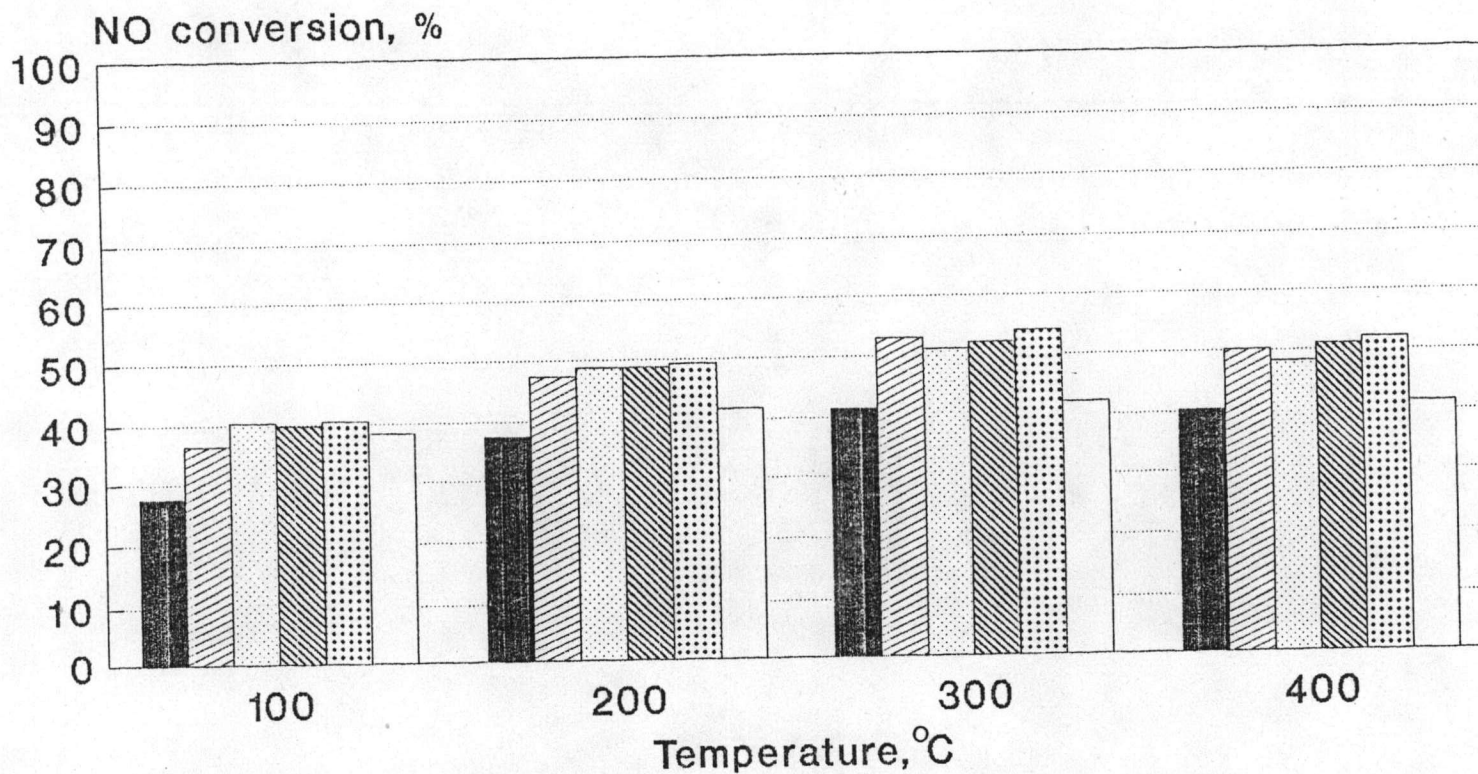


Figure 4.13 Catalytic activities of six catalysts on NO conversion in the absence of O<sub>2</sub>; SV = 18820 hr<sup>-1</sup>; concentration of NO and NH<sub>3</sub> in the feed : NO = 1149 ppm , NH<sub>3</sub> = 1149 ppm



# SPACE VELOCITY 37640 hr<sup>-1</sup>

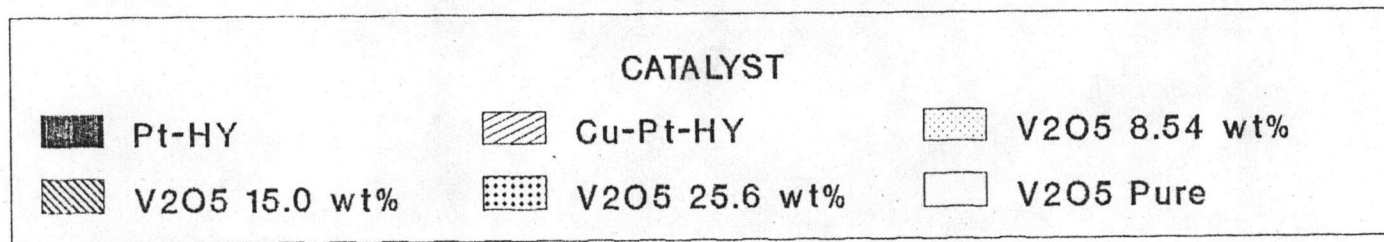
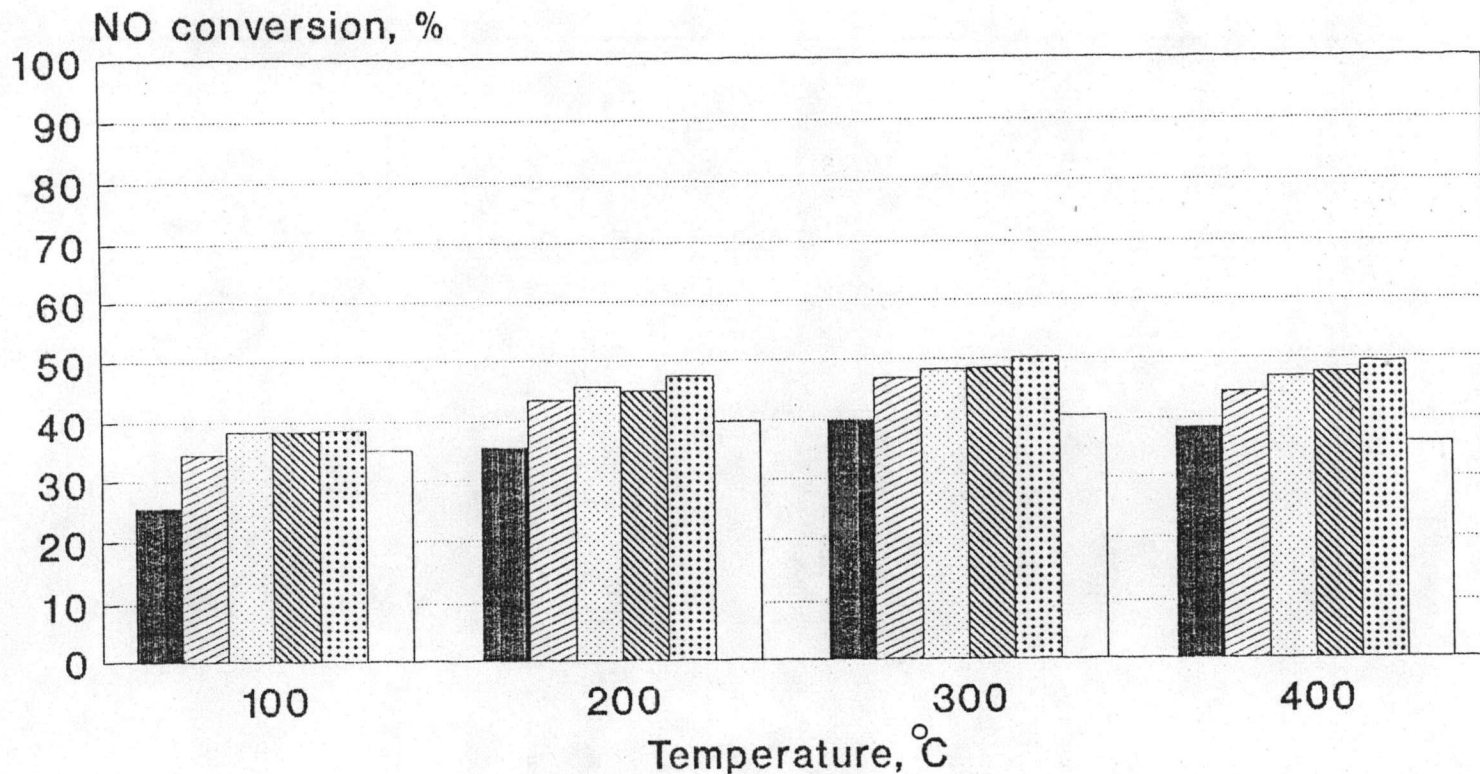


Figure 4.14 Catalytic activities of six catalysts on NO conversion in the absence of O<sub>2</sub>; SV = 37640 hr<sup>-1</sup>; concentration of NO and NH<sub>3</sub> in the feed : NO = 1149 ppm , NH<sub>3</sub> = 1149 ppm

# SPACE VELOCITY 56460 hr<sup>-1</sup>

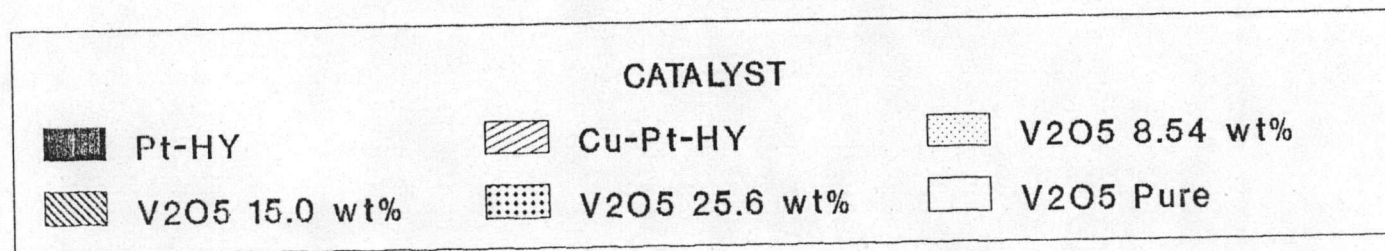
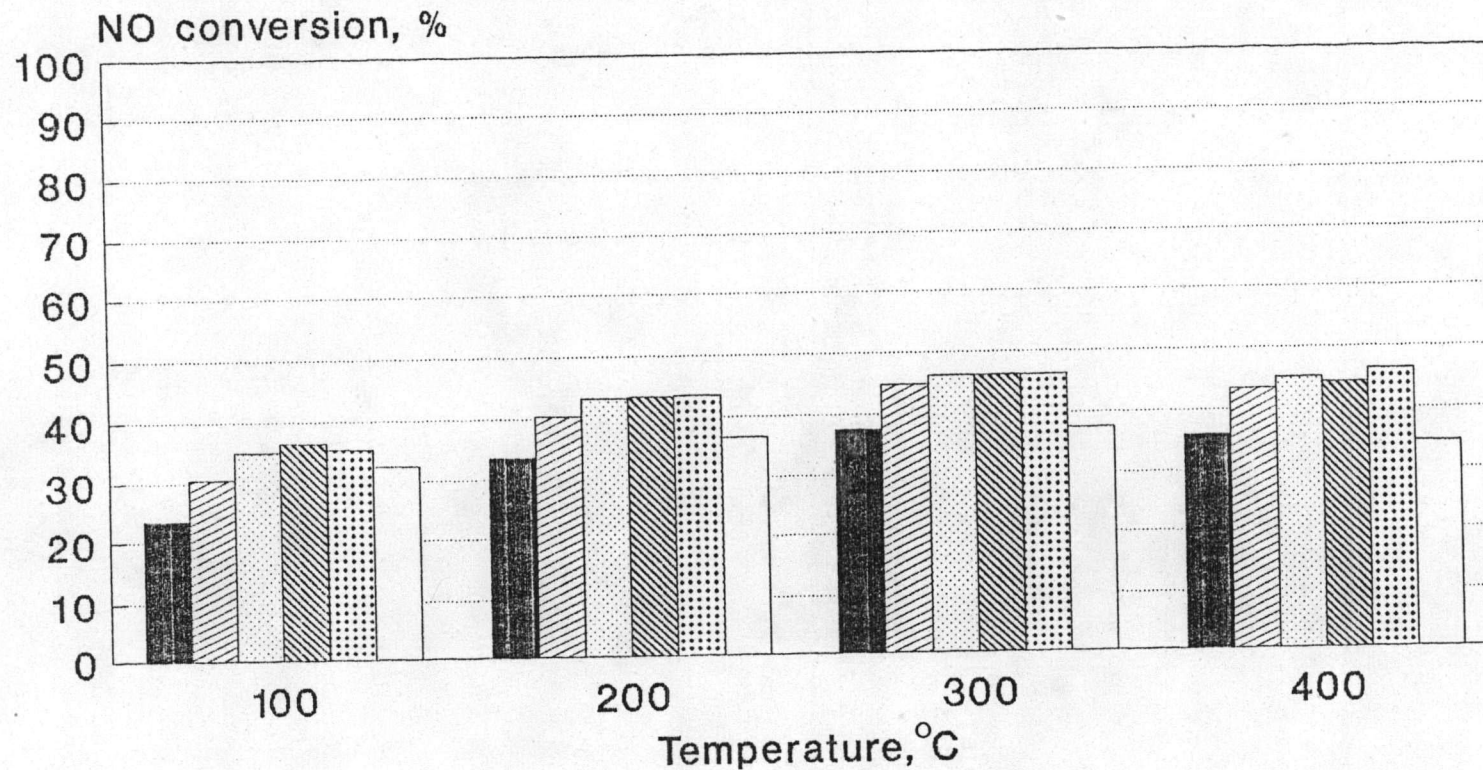


Figure 4.15 Catalytic activities of six catalysts on NO conversion in the absence of O<sub>2</sub>; SV = 56460 hr<sup>-1</sup>; concentration of NO and NH<sub>3</sub> in the feed : NO = 1149 ppm , NH<sub>3</sub> = 1149 ppm

# SPACE VELOCITY 75280 hr<sup>-1</sup>

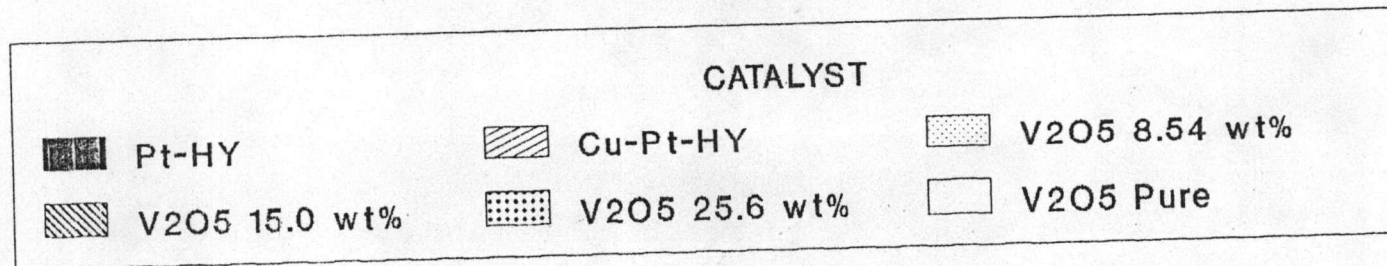
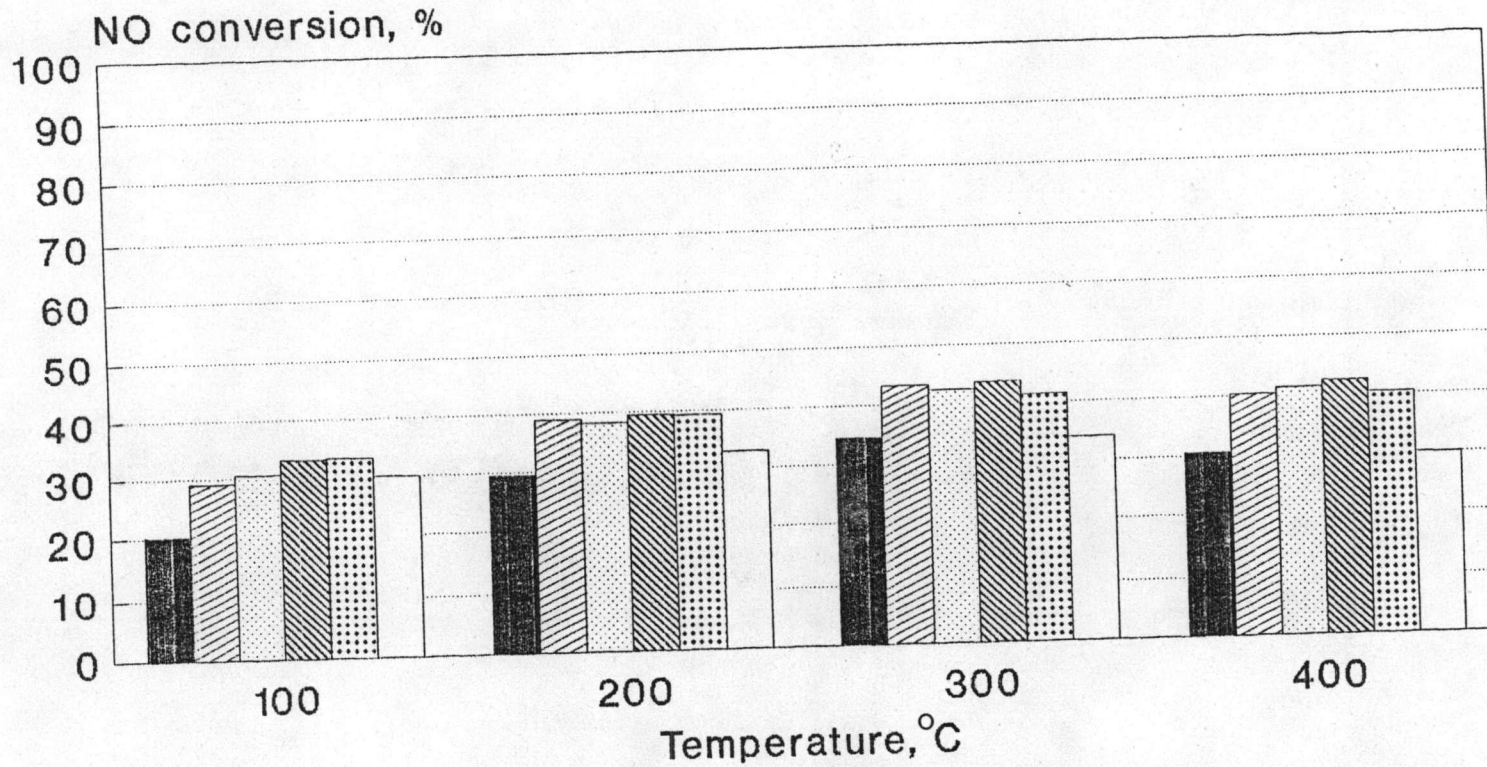


Figure 4.16 Catalytic activities of six catalysts on NO conversion in the absence of O<sub>2</sub>; SV = 75280 hr<sup>-1</sup>; concentration of NO and NH<sub>3</sub> in the feed : NO = 1149 ppm , NH<sub>3</sub> = 1149 ppm



SPACE VELOCITY 18820 hr<sup>-1</sup>

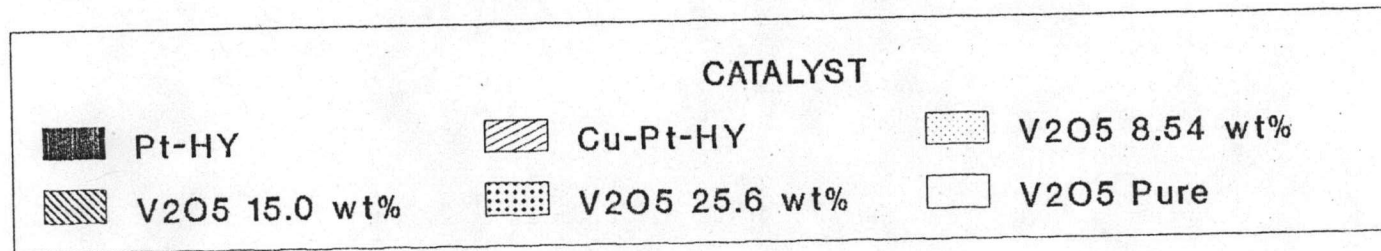
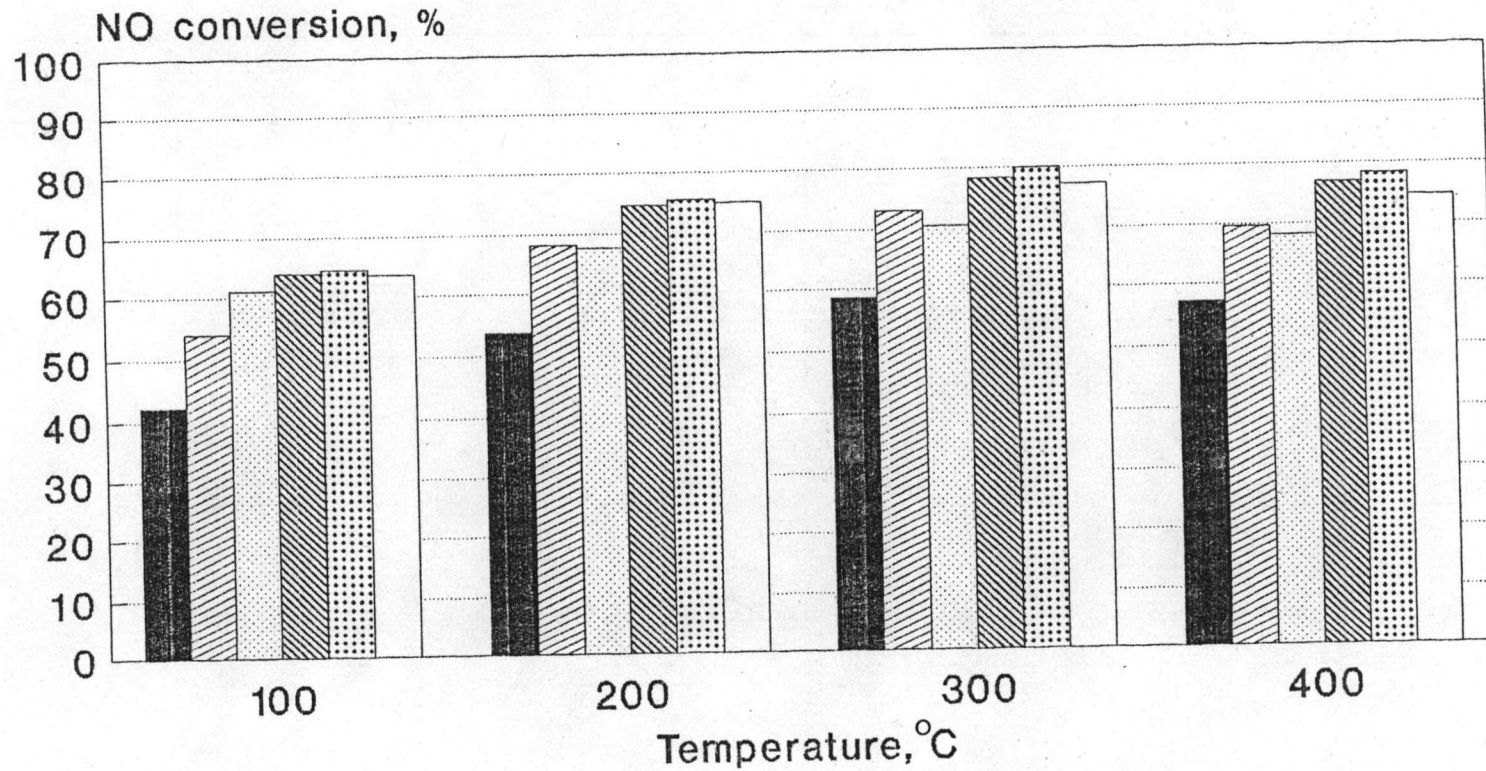


Figure 4.17 Catalytic activities of six catalysts on NO conversion in the presence of O<sub>2</sub>; SV = 18820 hr<sup>-1</sup>; concentration of NO and NH<sub>3</sub> in the feed : NO = 1149 ppm , NH<sub>3</sub> = 1149 ppm



## SPACE VELOCITY 37640 hr<sup>-1</sup>

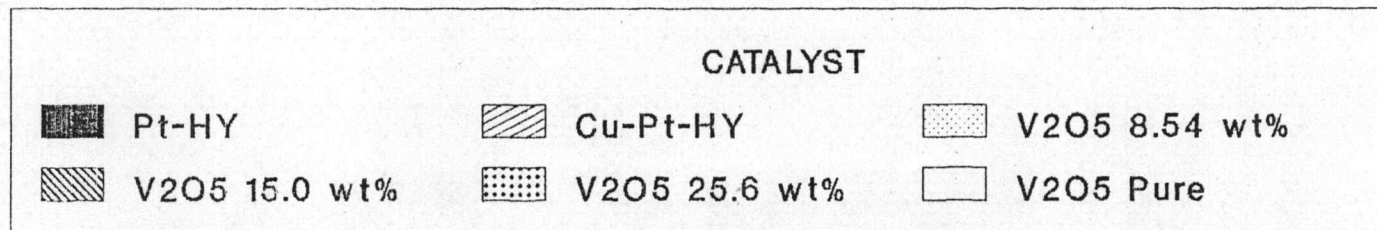
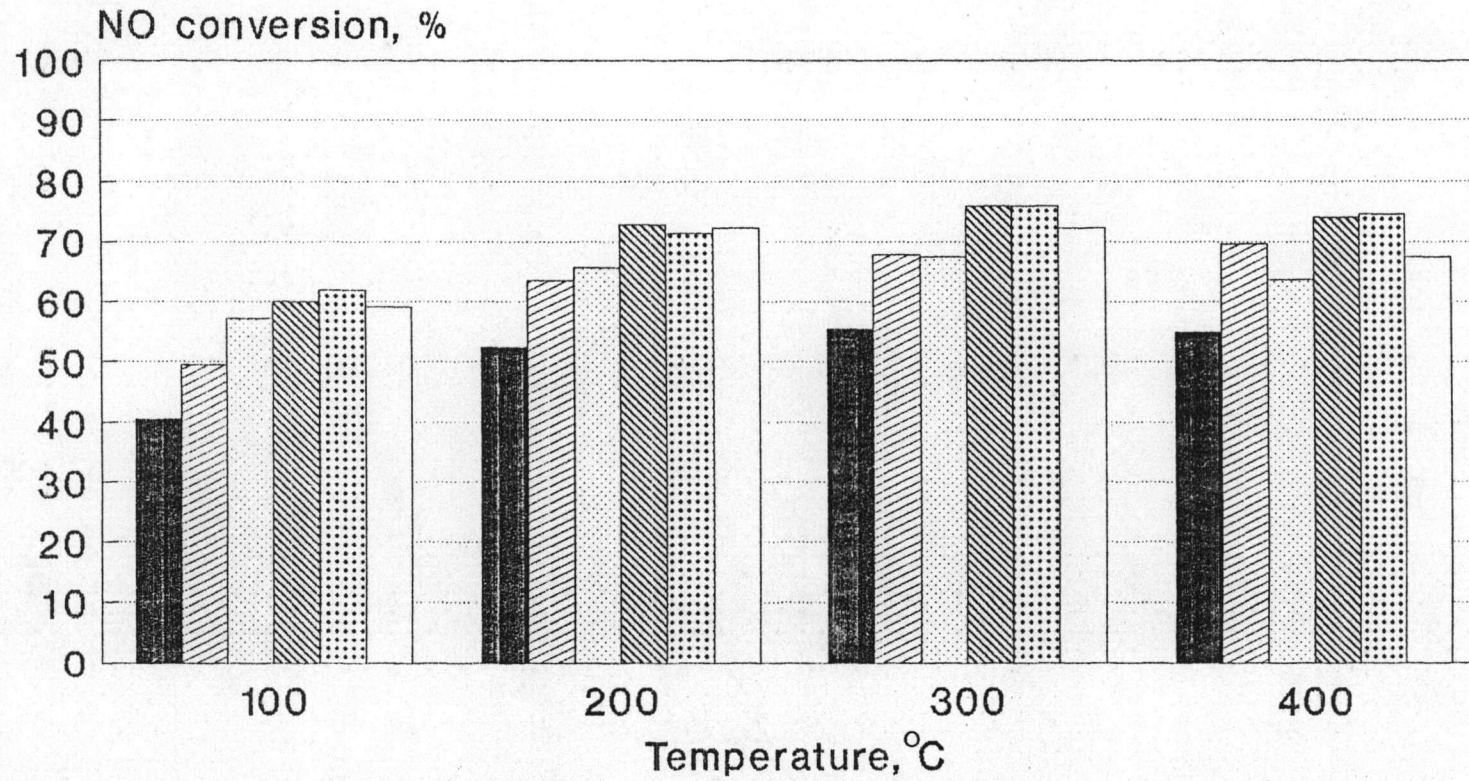


Figure 4.18 Catalytic activities of six catalysts on NO conversion in the presence of O<sub>2</sub>; SV = 37640 hr<sup>-1</sup>; concentration of NO and NH<sub>3</sub> in the feed : NO = 1149 ppm , NH<sub>3</sub> = 1149 ppm

# SPACE VELOCITY 56460 hr<sup>-1</sup>

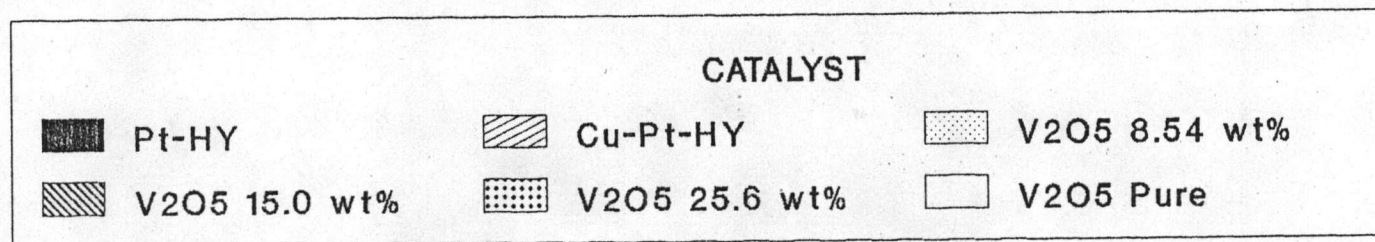
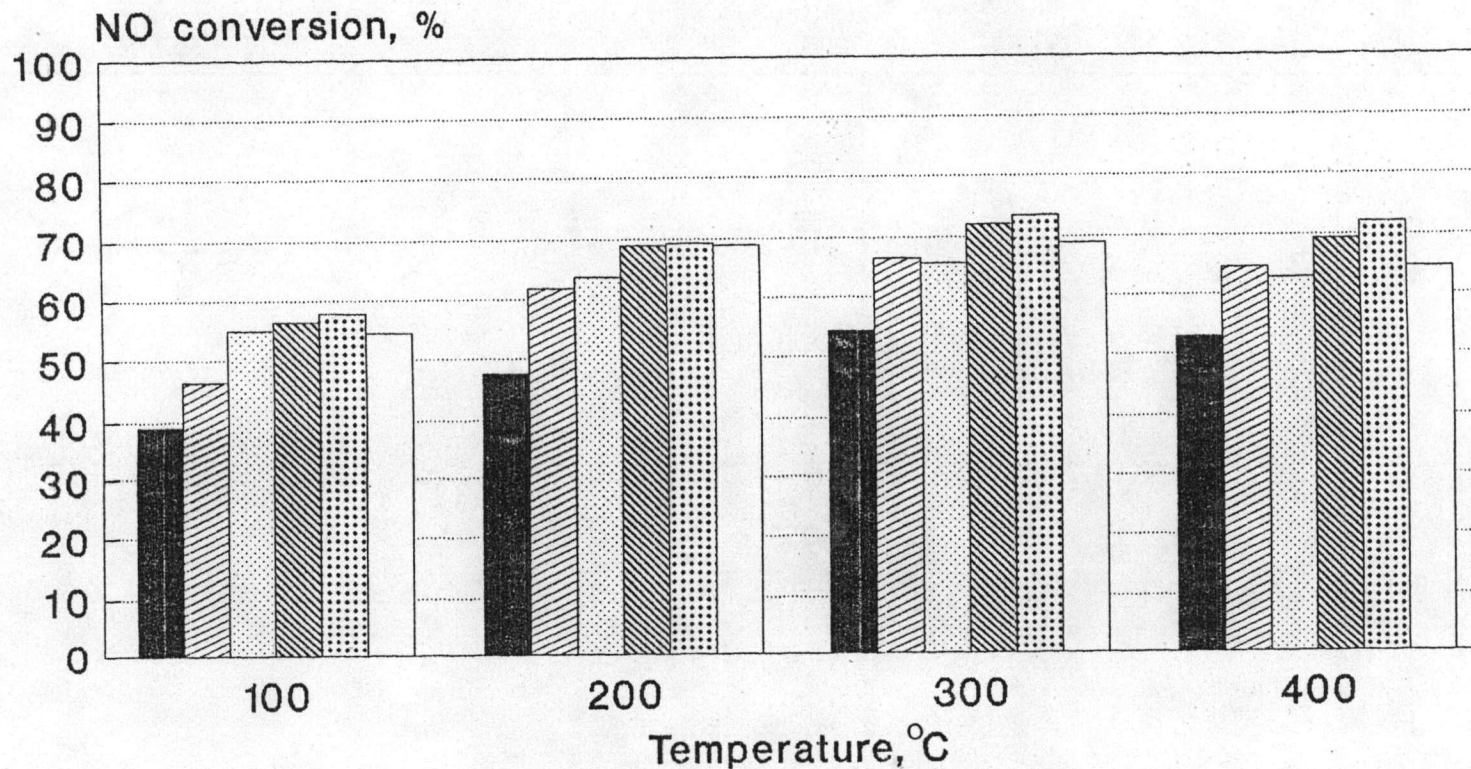


Figure 4.19 Catalytic activities of six catalysts on NO conversion in the presence of O<sub>2</sub>; SV = 56460 hr<sup>-1</sup>; concentration of NO and NH<sub>3</sub> in the feed : NO = 1149 ppm , NH<sub>3</sub> = 1149 ppm

## SPACE VELOCITY 75280 hr<sup>-1</sup>

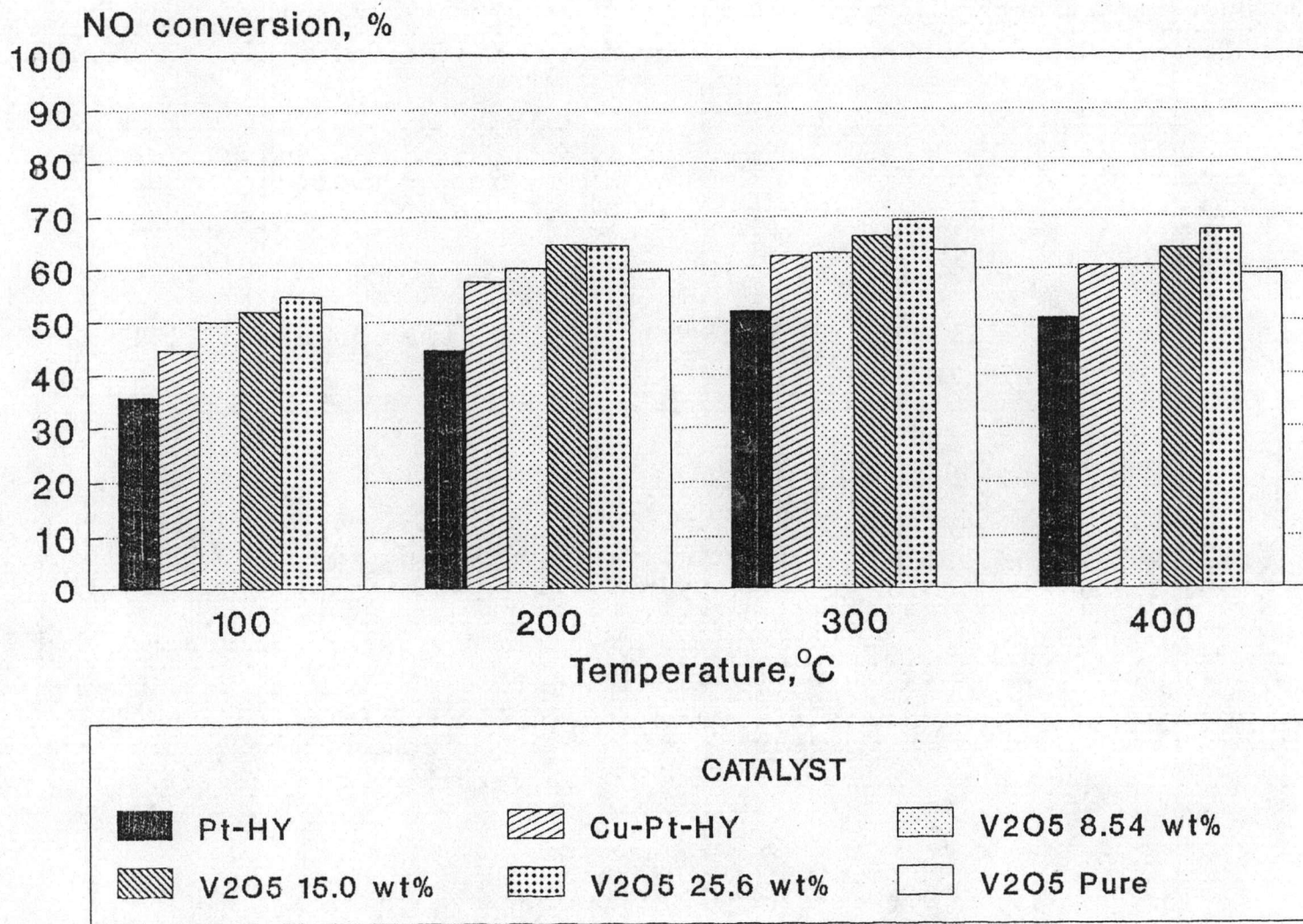


Figure 4.20 Catalytic activities of six catalysts on NO conversion in the presence of O<sub>2</sub>; SV = 75280 hr<sup>-1</sup>; concentration of NO and NH<sub>3</sub> in the feed : NO = 1149 ppm , NH<sub>3</sub> = 1149 ppm