CHAPTER V

ANALYSIS OF SIMULATION IN PRIMARY SMELTING REACTOR

In this chapter, the analysis of process parameters was investigated; the main adjusted parameters were varied in the specified range to study the effect of the important variables of the process which are the percentage of copper in white metal and slag, the percentage of magnetite in slag, the percentage of silica in slag and the bath temperature. In addition, the variations of the raw material, copper concentrate, were also investigated. After the simulations, the conclusion is obtained in a simplified table in order to guide the production line in its operations.

The composition of copper concentrates varies from many sources in the world so that the impact of different chemical compositions mainly %Cu, %Fe and %S were investigated. Table 5-1 shows the composition of the copper concentrates which are used in this study. The main mineral components in copper concentrate such Chalcopyrite, Chalcosite, Covellite, Bornite, Pyrotite and Pyrite have been calculated to approximate 25%, 30% and 35% of Cu, Fe and S respectively. It is noted that the natural composition of the concentrate are not the same as this study but in order to illustrate the effect of chemical composition and the consequent calculation of mineralogical composition, the changes in the copper, iron, sulfur and silica has to be made. These species significantly affect the parameter of smelting process.

It can be seen from Table 5-1 that the copper concentrate has 3 main groups, copper variation group, iron variation group and sulfur variation group which vary the elemental content from 25 to 35% while keeping the other parameters constant. In these three groups, the energy factor to determine the thermal balance in the furnace was calculated. Likewise, the slag factor related to the capacity of the electric slag cleaning furnace was determined.

The simulation model however has its limitations and there are also assumptions used in the calculations. The results may not necessarily be in agreement with the actual operations but can be used as a guide for understanding the process control and operation.

Table 5-1: Chemical and mineralogical composition of copper concentrates

Composition	Formula	25% Cu	30% Cu	35% Cu	25% Fe	30% Fe	35% Fe	25% S	30% S	35% S
Chemical Composition (%)										
Copper	Cu	25	30	35	28	28	28	28	28	28
Iron	Fe	26	26	26	25	30	35	26	26	26
Sulfur	S	30	30	30	30	30	30	25	30	35
Silica	SiO_2	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Gangue										
Energy Factor	**S/Cu**	1.2	1.0	0.9	1.1	1.1	1.1	0.9	1.1	1.3
Slag Factor	**Fe/Cu**	1.1	0.9	0.7	0.9	1.1	1.3	0.9	0.9	0.9
Mineralogical Composition (%)										
Chalcopyrite	$CuFeS_2$	60	43	25	71	40	15	23	58.9	0
Chalcosite	Cu_2S	0.5	6	13	2	16	15	24.5	3.4	0
Covellite	CuS	1	1	0	3	0		0	1.5	0
Bornite	Cu_5FeS_4	5	15	25	0	2	17	0.5	5.93	44
Pyrrotite	FeS	3	8.5	14	0	19.5	42	26.2	4.6	0
Pyrite	FeS_2	12	13	14	7.5	10.5	4	4.5	9.5	45

Table 5-2 shows the operation range of the adjusted parameters or manipulated parameters that the operator can be changed to continue stable operation without production interruption. These parameters are the main variables that were studied to control the process.

Table 5-2: Operation range for simulation (Adjusted Parameter)

No.	Parameter	Nominal	Variation Range
Adjusted Parameter			
1	Dry concentrate feed rate	70 tph	60 - 80 tph
2	Oxygen flow rate	9,836 Nm^3/hr	6,000 - 10,000 Nm^3/hr
3	Blowing air flow rate	35,000 Nm^3/hr	30,000 - 38,000 Nm^3/hr
4	Flux feed rate	6 tph	2 - 10 tph
5	Revert feed rate	0 tph	0 - 20 tph

Table 5-3: Standard conditions for simulation (Constant Parameter)

Parameter	Value
Injection air flow rate	2,500 Nm^3/hr
Garr gun air flow rate	4,000 Nm^3/hr
Annular air	2,500 Nm^3/hr

In addition, the simulation of this chapter is based on the standard condition as shown in Table 5-3. These figures are collected from nominal plant design and actual plant data. They are the constant parameters or parameters that should remain constant during the process.

5.1 Variation of copper in copper concentrate

In these topics, the PSR model simulated the process of primary smelting by varying the operation parameters such as the concentrate feed rate, oxygen flow rate, blowing air flow rate, flux feed rate and revert feed rate and relate with the controlled parameters which are the %Cu in white metal and slag and the Fe_3O_4 and SiO_2 in slag. In addition, the %Cu in concentrate is also varied to analyze the effect of low content, normal content and high content of copper in concentrate. Furthermore, the yield of PSR reactor was also calculated by comparing the loss of copper in each case. The formula of the yield is obtained by total copper in white metal divided by total of copper input which were come from copper concentrate and revert.

5.1.1 Effect of concentrate feed rate

Figure 5-1 (a) through 5-1 (f) shows the effects of the variation %Cu in copper concentrate from 25 to 35% and feed rate of copper concentrate from 60 to 80 tph on the various parameters. The trend for the increase in the concentrate feed rate increases the %Cu in white metal slightly when compare with trend for increase %Cu in copper concentrate. It can be seen from Figure 5-1 (a) that an increase of 5 tph in the concentrate feed rate can increase the %Cu in the white metal by 0.1% whereas a 5% increase in the copper content in the concentrate increase can increase the %Cu in white metal by 1%. This is mainly due to higher amount of pyritic sulfur combustion with oxidation of chalcopyrite, covellite, bornite and chalcocite which consist of copper. The more quantity of copper in concentrate can increase copper in the white metal and consequently have more effect on the %composition of the white metal than the feed rate.

Increasing the concentrate feed rate also increases the %Cu in slag slightly because the amount of white metal distributed to slag phase is also slightly increased. At the same time, while the slag forming reaction is still the same, there is also an increase in the quantity of slag formed. The combined effects results in a slightly increase percentage of copper in slag phase. In comparison, with the higher copper content in concentrate, there is higher copper loss in slag than with the increase concentrate feed rate. As seen from Figure 5-1 (b), the copper content of concentrate that increased by 5% will result in an increase of about 1.5% in the %Cu in slag due to the higher amount and copper content of white metal.

It is shown from the trends in Figure 5-1 (c) that the amount of Fe_3O_4 is slightly increased when increasing the concentrate feed rate and copper composition in dry concentrate. The slag production increases with increase in concentrate fed rate. The copper concentrate with the 25% copper has the lowest magnetite content. It is possible what with the lower %Cu in the white metal, the FeO for slag forming reaction is also at its lowest and magnetite content is also reduced consequently.

On the other hand, the amount of SiO_2 in the slag shows a decreasing trend as shown in Figure 5-1 (d) because of increasing amount of FeO in slag and the addition of slag forming reaction. It should also be noted that 25%copper content have highest $\%SiO_2$ in slag based on the assumption that the gangue composition which is the balance in the concentrate is represented by silica so that the concentrate with less copper have more silica content and does not need to react with the natural silica.

The effect of increasing concentrate feed rate and %Cu in concentrate related to the bath temperature shows an increasing trend as seen in Figure 5-1 (e). This is the consequence of the higher net heat generated by copper concentrate increases from the pyritic sulfur combustion. It is noted that the proportion of increasing %Cu in concentrate from 25% to 30% has the different range when compared with the 30 and 35 percent range. This could be due to the differences in mineralogical composition as the copper in the concentrate increases.

As a consequence of the higher bath temperature with higher concentrate feed rate, the yield in the PSR is also showing an increasing trend.

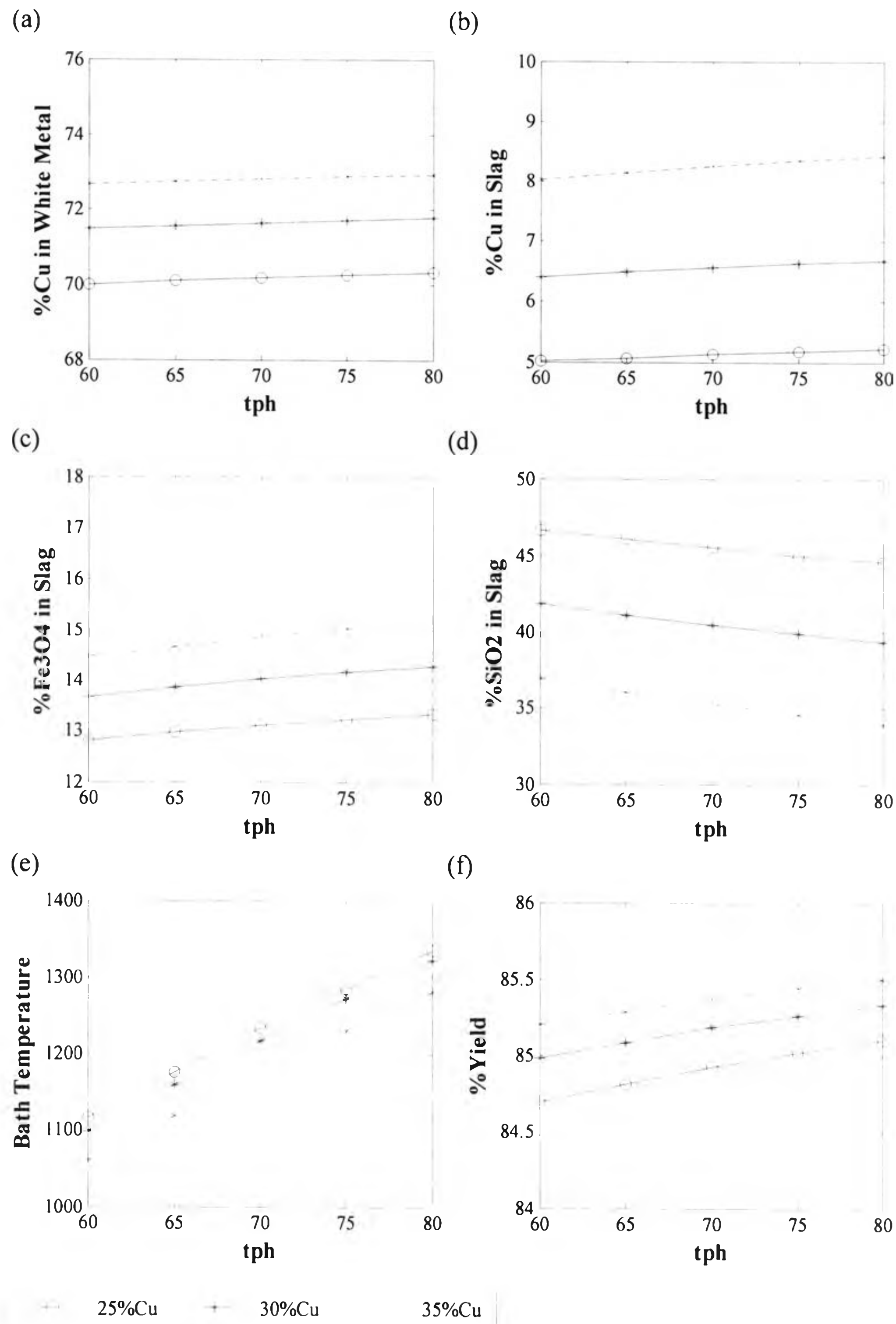

Figure 5-1 (a) – (f): Variation of copper concentrate feed rate and %Cu in concentrate

5.1.2 Effect of industrial oxygen flow rate

The oxygen supply to the furnace is one of the most important parameters in PSR because the most important reactions use oxygen and generate enough heat for autogenous operation. For this reason, the optimum oxygen supply to the furnace should be calculated. Oxygen comes from two sources, industrial oxygen and blowing air. This study will investigated the variations of oxygen and blowing air as the adjusted parameters.

There is moderate change in the percentage copper in white metal with variations in the oxygen flow rate because the quantity of copper that react with oxygen is still the same and the use of oxygen is in the same proportion. The unreacted oxygen goes to the off gas stream. The utilization of oxygen in the reactor is called oxygen efficiency and is about 95% in Teniente Converter. In normal operations, for every copper concentrate blend, the oxygen coefficient which calculates the required oxygen for pyritic sulfur combustion and slag forming reaction per one ton of concentrate feed is determined. The calculation for the oxygen coefficient is shown as follow;

Coefficient of oxygen = Volume of oxygen use (Nm^3) per ton concentrate feed

The coefficient of oxygen in this simulation cases is increasing as a consequence of the increase in industrial oxygen flow rate since the concentrate feed rate is held constant. Normally, when PSR is operated with higher coefficient of oxygen than the required from each of concentrate; it will be result in higher %Cu in white metal and higher temperature.

The effect of changing the oxygen flow rate on the % Cu in slag shows a flat trend as shown in Figure 5-2 (b). Concentrates with higher copper content will have more copper loss in slag because the quantity of white metal is increasing and the amount of white metal distributed to slag increases consequently.

It should be considered that the simulation in this case as shown in Figure 5-2 (a) to (c) that there are no significant consequences with white metal and slag quality (%Cu, %Fe_3O_4, SiO_2) due to the fixed extent of reaction as assumed from the model in Chapter 4. It is assume that when all copper and iron react with oxygen in the simulated extend of reaction, all other excess oxygen added will not be reacting any further but goes to the off gas system. Furthermore, with the same standard condition as shown in Table 4-6 will result in the same mechanism in the furnace and there will be no further effect with extent of reaction in PSR. However, the trend in the silica content as shown in Figure 5-2 (d) has the different result due to the copper in concentrate. The concentrate with 25% copper content has the lowest silica content in slag on the assumption for calculation of this model that calculated gangue mineralogy as silica. The Figure 5-2 (a) to (e) will illustrate these results. Additionally, the range of oxygen flow rate which was varied form 7,000 – 10,000 Nm^3/hr, is high enough to make oxygen react with FeO completely and result in constant $\%Fe_3O_4$ in slag as shown in equation (5-1) and (5-2).

Slag forming reaction;

$$2FeO + SiO_2 \rightarrow 2FeO.SiO_2 \quad \textbf{(5-1)}$$

Remaining FeO reaction;

$$FeO + O_2 \rightarrow Fe_3O_4 \quad \textbf{(5-2)}$$

In a typical plant operation, changing of oxygen or blowing air flow rate can cause consequent changes in the copper in white metal. The significance of oxygen flow rate can not be described from this model because of the different standard condition. For further study, an analysis of changing standard condition together with this study or install a controller to vary the oxygen efficiency in the model. However, varying the oxygen efficiency will be result in changing the extent of reaction particularly the FeS oxidation, which determines the %Cu in white metal. This means that there will be different standard conditions.

The effect of oxygen coefficient on the bath temperature was shown in Figure 5-2 (e). The temperature is decreasing when flow of oxygen is rising because the oxygen from 7,000 Nm^3/hr is not enough to react with concentrate. Increasing the oxygen further will not result in further reaction so that the heat is lost for the heat up of the furnace and to the ambient atmosphere.

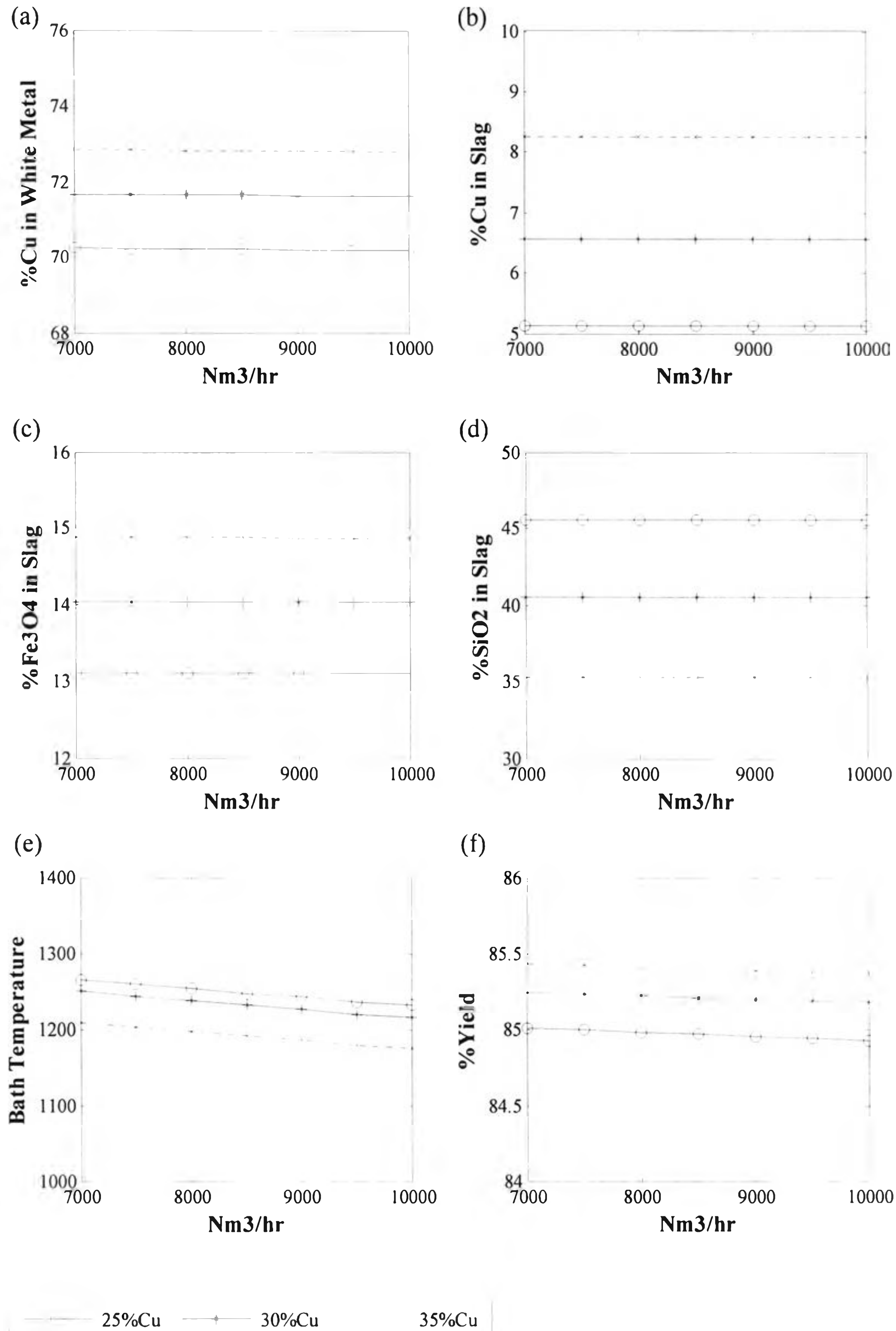

Figure 5-2 (a) – (f): Variation of industrial oxygen flow rate and %Cu in concentrate

5.1.3 Effect of blowing air flow rate

There is only minor variation in the composition of white metal and slag caused by the increasing of blowing air flow rate because of the limitation of copper and iron content in concentrate which is the same amount for constant concentrate feed rate. It is noted that the model has limitation from fixing extent of reaction as describe in topic 5.1.2 and does not include thermodynamic consideration so that it requires the validation with the actual plant data. Figure 5-3 (a) – (f) shows the result of the variation of blowing air flow rate.

In Figure 5-3 (e), the trend of increasing blowing air flow rate decreases bath temperature because of the increasing amount of inert nitrogen gas that is required heat and rise to the operating temperature. This variation has more influence on the bath temperature than oxygen flow rate because the amount of flow rate was varied in 2,000 Nm^3/hr ranges and results in more inert nitrogen flow rate. In addition, the result of %copper concentrate variation from Figure 5.3 (e) shows that the 25% copper content results in temperature profile closer to 30% copper content. Consequently, the temperature of PSR cannot be estimated from %copper content of concentrate alone but has to consider the whole energy balance of the furnace.

In comparison with oxygen flow rate, the variation of blowing air flow rate has more significant effect with furnace temperature than oxygen flow rate due to the amount of inert nitrogen gas present.

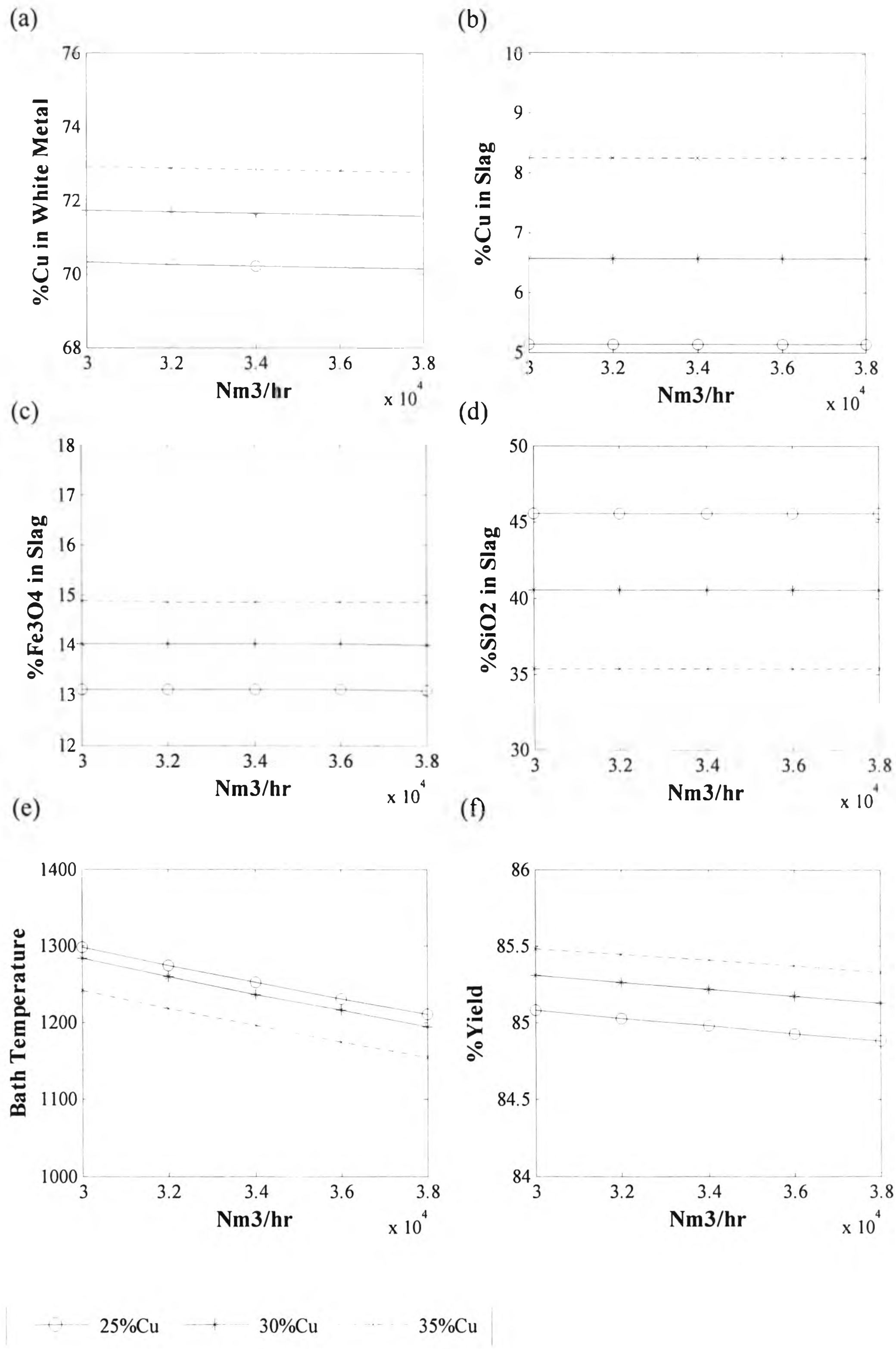

Figure 5-3 (a) – (f): Variation of blowing air flow rate and %Cu in concentrate

5.1.4 Effect of flux feed rate

It can be seen from the trends in Figure 5-4 (a) that there is no effect of flux addition with copper in white metal. With increase feed rate of flux, the silica in flux react with iron oxide to form slag and have no consequence with white metal which is mainly composed of copper sulfide and iron sulfide. It is noted also that the effects of equilibrium is not considered in this case. Theoretically, the phase equilibrium of FeS – SiO_2 – FeO in slag should be considered.

It can be seen from the trends in Figure 5-4 (b) that the %Cu in slag is decreasing with increasing flux feed rate because the volume of slag increases with the addition of silica. The quantity of white metal that distribute to slag phase is still the same so that the proportion of copper in slag decreases.

Figures 5-4 (c) to 5-4 (e) shows that flux feed rate below 4 tph results in high temperature and magnetite. The high magnetite forming reaction consumes heat to generate magnetite. This reaction happens because the silica added is not enough to form fayalite slag and the remaining FeO is over oxidized to form Fe_3O_4. After the feed rate is increased to more than 4 tph, the quantity of silica was suficient to react with FeO to produce fayalite slag and the magnetite content was reduced gradually. In Figure 5-4 (d), the trend shows the opposite way. As more silica is added in excess, the silica goes to the slag phase.

It should be noted that the model assumed gangue content as silica so that silica addition is rather high compared with the actual operations.

For yield of PSR, it can be seen from the trends in Figure 5-4 (f) that flux feed rate is not influence with yield because it has no significant effect on %Cu in white metal as shown in Figure 5-4 (a). Generally, silica flux has more influence on the slag quality and quantity.

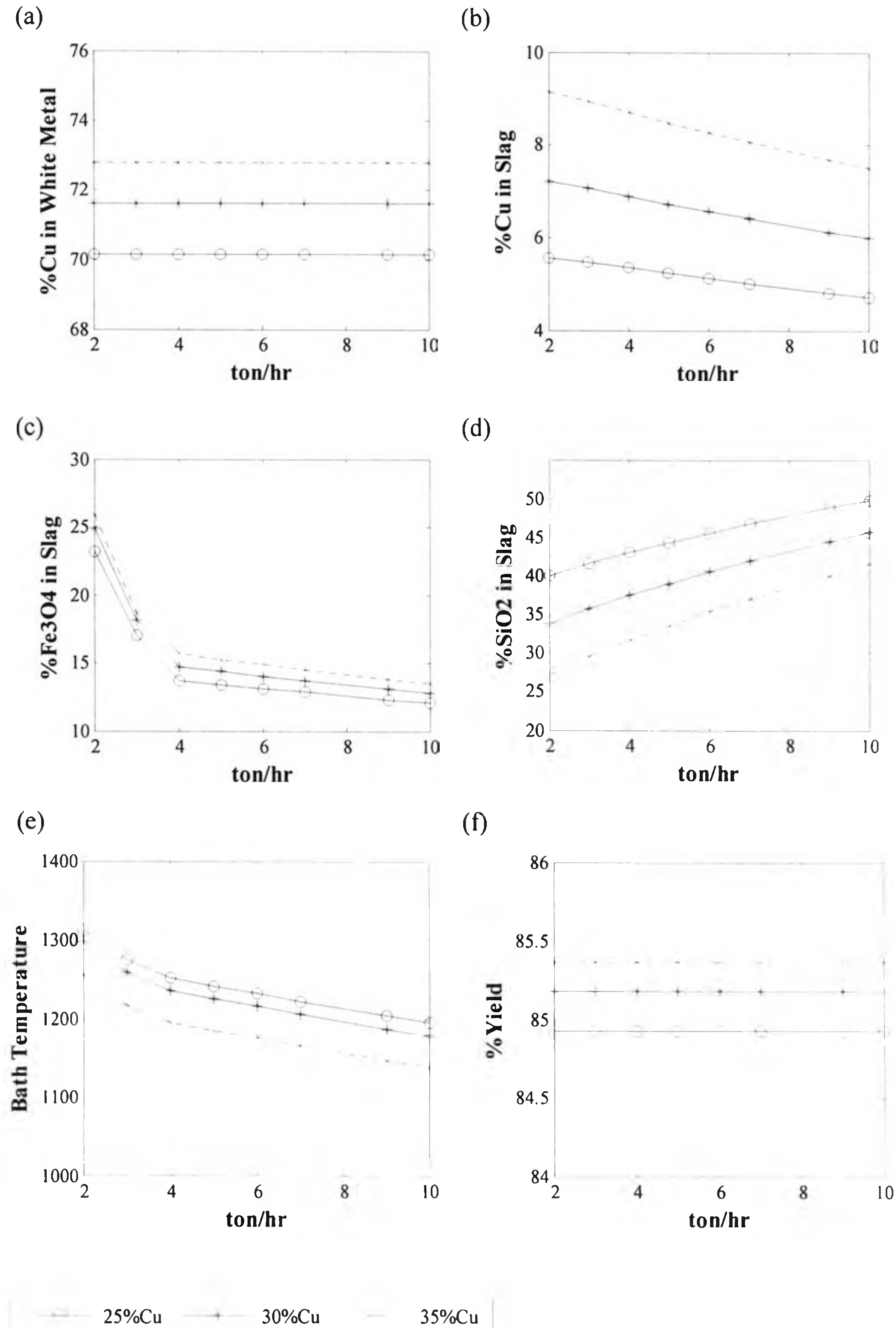

Figure 5-4 (a) – (f): Variation of silica flux feed rate and %Cu in copper concentrate

5.1.5 Effect of revert feed rate

The composition of revert for this simulation is shown in Table 4-3. Analysis of variation in revert feed rate is determined based on the design capacity, 0 – 20 tph. The purpose of revert addition to furnace is to recover the copper in the smelting process and control temperature of the furnace. The composition and quantity of the reverts added have many effects in process as shown in Figure 5-5 (a) to 5-5 (e).

It can be seen from the trends in Figure 5-5 (a) that %Cu in white metal increase with revert addition. The copper sulfide in revert, when melted, goes to white metal phase directly and the other copper bearing materials (copper oxide) react in the following reaction then separate to either white metal or slag phase;

For Cu in Cu_2S;

Cu_2S (solid)	→ Cu_2S (white metal)	**(5-3)**

For Cu in Cu_2O;

Cu_2O (solid) + FeS (solid)	→ Cu_2S (white metal) + FeO (slag)	**(5-4)**
Cu_2O (solid)	→ Cu_2O (slag)	**(5-5)**
CuO (solid)	→ CuO (slag)	**(5-6)**

The effect of reverts addition to the %Cu in slag has shown in Figure 5-5 (b). It shows that the low content of copper concentrate (25%Cu) is more sensitive than the higher copper content concentrate. It shows higher %Cu in the slag. Consequently, the addition of revert in high content of copper will not have much bearing with the %Cu in slag.

Figure 5-5 (c) trends show increasing Fe_3O_4 in slag with increasing revert feed rate. The magnetite present in revert is melted and will dissolved in slag phase. In Figure 5-5 (d), the reduction of silica in slag from the addition of revert is the effect of slag forming reaction where the amount of FeS is increasing from revert melting and consume silica to form slag.

Figure 5-5 (e) shows that the trend in the bath temperature decreases while the feed rate of revert is increased. This is consistent with more heat required to melt reverts. It is noted that the adjustment of revert feed rate is used to control the bath temperature when it goes higher than 1250°C. Lower than this temperature, the reverts feed rate should not be adjusted. The model calculation basis is on a daily operation so that 2 to tph of revert addition is equal to 48 ton per day. To use this figure would result in a temperature drop of about 25°C.

The effect of reverts addition to the PSR yield is shown in Figure 5-5 (f). When the revert feed rate is more than 10 ton/hr, the rate of yield increase is lower than compared with the 0-10 ton/hr. The addition of more revert to the reactor can improve yield because the copper in revert react and increase the copper sulfide in white metal as shown in equation (5-3) and (5-4). However, copper in slag also increases from the amount of copper oxide in equation (5-5) and (5-6). However, the amount of copper oxide in revert is less than copper sulfide as defined in Table 4-3 so that there is still an improvement in the yield.

It is noted that revert composition has significant impact with the yield so that the analysis of revert should have a certain level of accuracy. In this study, revert composition was obtained by reconciling with the laboratory data where the analysis of Cu, Fe, S, Fe_3O_4 are determined.

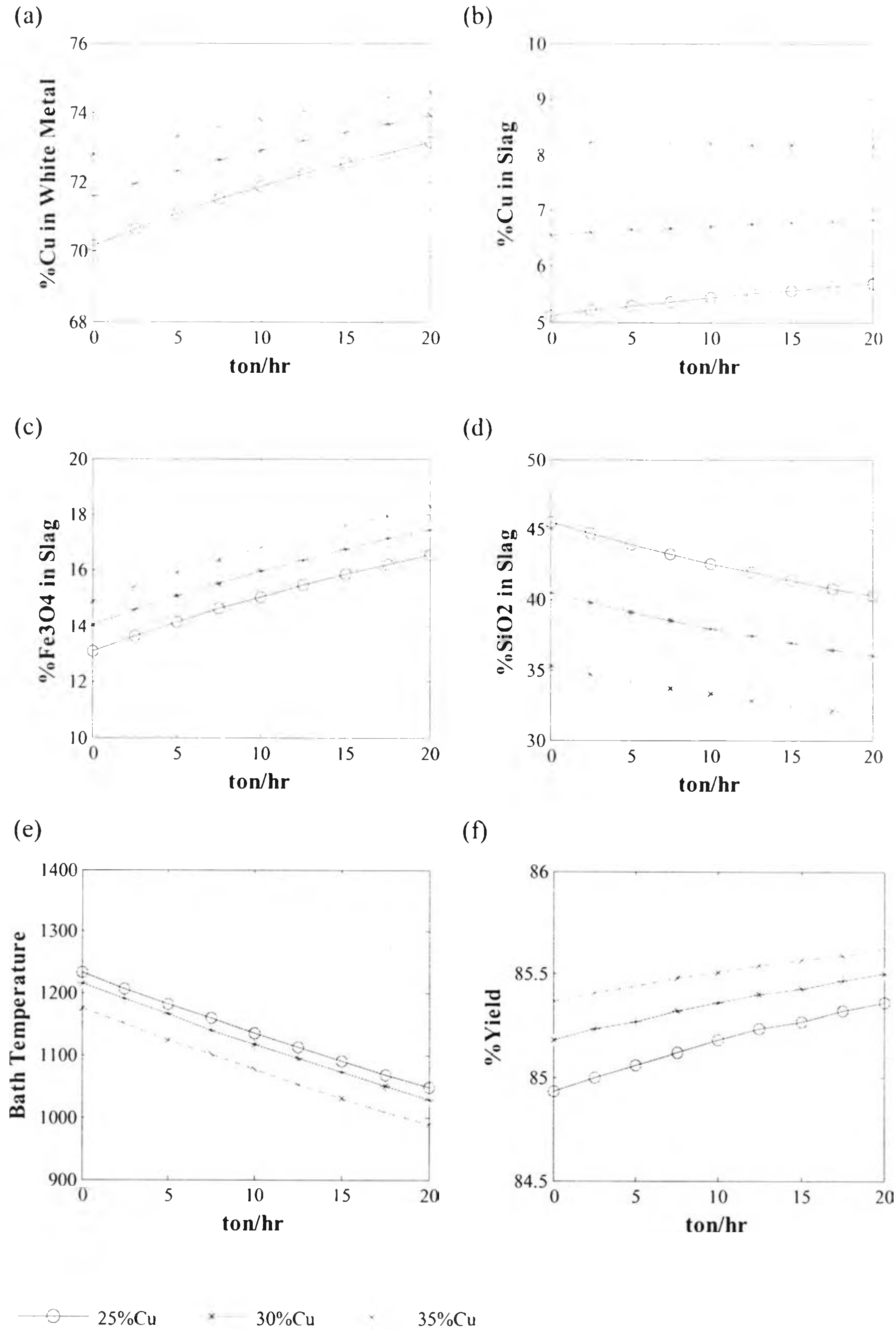

Figure 5-5 (a) – (f): Variation of revert feed rate and %Cu in copper concentrate

5.2 Variation of iron in copper concentrate

Iron in copper concentrate is the important element to consider in smelting process because the major component of slag consists of iron. The volume of slag produced determines the slag cleaning equipment capacity. Figure 5-6 (a) through 5-10 (f) show the result of varying the %Fe in copper concentrate from 25 to 35% with the other parameters.

5.2.1 Effect of concentrate feed rate

The effect of copper concentrate feed rate from 60 to 80 tph on the %Cu in white metal, %Cu in slag, furnace temperature, %magnetite in slag, $\%SiO_2$ in slag and reactor yield are shown in Figure 5-6 (a) – (f).

The white metal copper grade shows an increasing trend with increasing concentrate feed rate. However, it can be seen from Figure 5-6 (a) that a 5% increase of Fe in concentrate decreases the white metal grade about 1%Cu. It could be explained by the amount of iron sulfide combustion coming from the oxidation of pyrotite and pyrite. Pyrite and pyrotite consist of iron so that the more quantity of iron in concentrate can decrease copper in white metal. This is opposite to the effect of copper with increasing concentrate feed rate on the %Cu in white metal.

Increasing the concentrate feed rate can increase %Cu in slag slightly because the amount of white metal distributed to slag phase is increasing while the amount of slag forming reaction is still the same. Comparing the different concentrate grades, the concentrate with higher iron content can results in lower copper loss in slag. Because %Cu in white metal increase but the quantity of slag increases too, this result in slightly increasing percentage of copper in slag phase. However, it can be seen from Figure 5-6 (b) that the iron content of concentrate that increased about 5% resulted in a reduction of copper in slag but is not so significant.

It was shown in Figure 5-6 (c) that the amount of Fe_3O_4 is slightly increased with the increase in concentrate feed rate and percentage of iron composition in dry concentrate. It is expected that slag production increases with increase in concentrate feed rate. The concentrate with 35%Fe in concentrate has highest content of magnetite in slag because of high content of FeO coming from high iron sulfide content of white metal. At the concentrate feed rate above 70 tph and 35%Fe content, the %magnetite is rising highest. In the opposite way, the amount of SiO_2 is decreased because of increasing amount of FeO in slag and the addition of slag forming reaction. Similarly, %Fe in concentrate has a decreasing trend with $\%SiO_2$ as shown in Figure 5-6 (d). The concentrate with 25%iron content have highest $\%SiO_2$ in slag for the same reason as mentioned before. The model assumed that the gangue composition which makes the balance in the concentrate is mainly silica so that the less copper, the more silica content which does not react as the natural silica.

The effect of increasing concentrate feed rate and %Fe in concentrate with the bath temperature shows an increasing trend as seen in Figure 5-6 (e). The net heat generated by copper concentrate reactions is increased from the pyritic sulfur combustion. It is noted that the proportion of the %Fe in concentrate from 25% to 30% is slightly different from the 30 and 35 percent and is the influence of mineralogical composition changes with increasing rates.

The yield of PSR is increasing while concentrate feed rate is rising due to the effect of increasing %Cu in the white metal. Also, the lower yield of the concentrate with lower %Fe in concentrate is mainly due to the higher copper in white metal.

For this simulation on the effect of % Fe and copper concentrate feed rate, the most significant is in the bath temperature as shown in Figure 5-6 (f). With the heat generation increasing and the iron content in concentrate is increasing, the copper in product is also increasing.

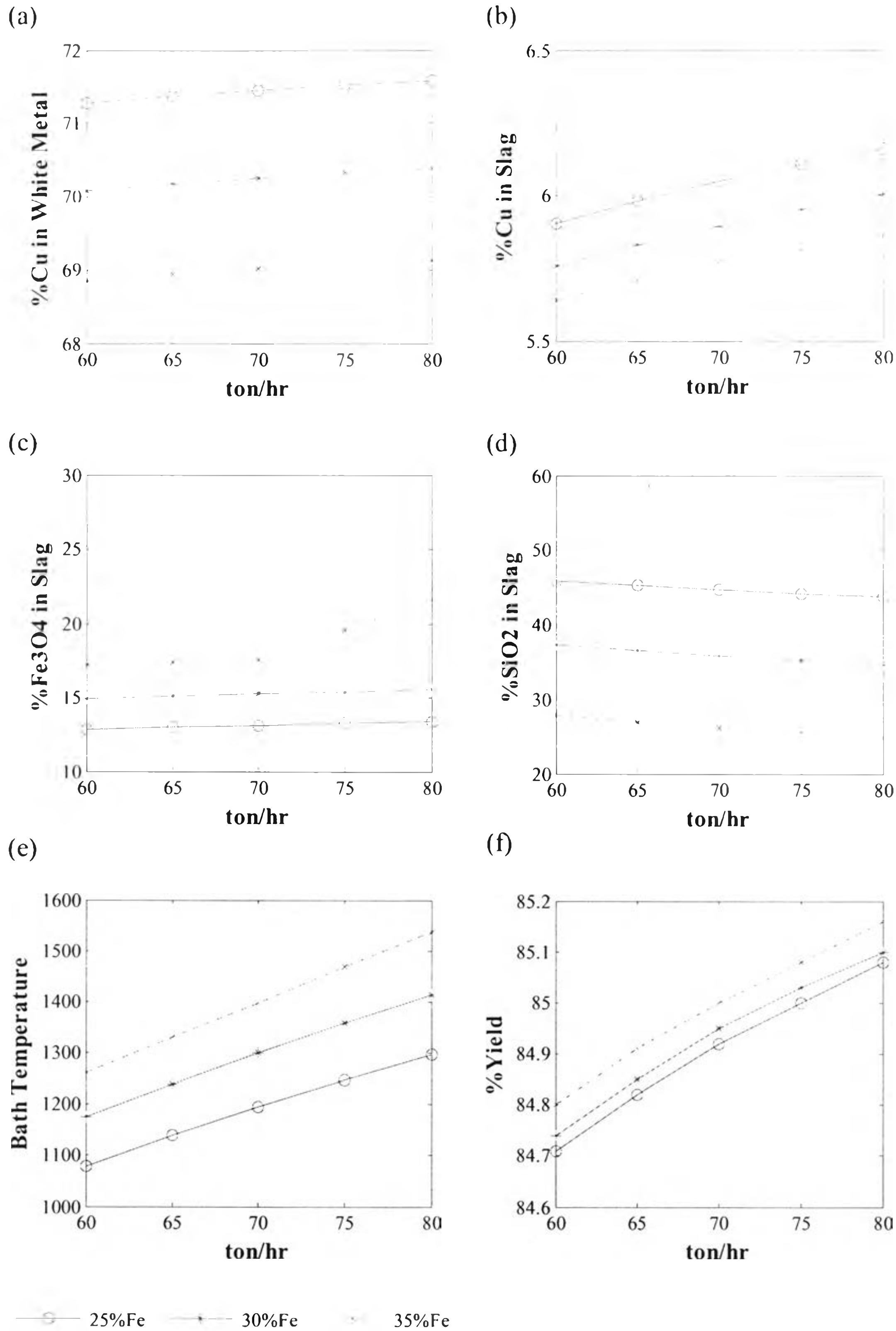

Figure 5-6 (a) – (f): Variation of copper concentrate feed rate and %Fe in copper concentrate

5.2.2 Effect of industrial oxygen flow rate

The oxygen supply to the furnace and iron content in copper concentrate are investigated in this section and the result was shown in Figure 5.7 (a) – (f).

Changing oxygen flow rate causes no effect of composition in white metal and slag because of the fixed extent of reaction which was described in 5.1.2. The higher percentage of iron in concentrates, the less copper content in white metal and slag because quantity of iron sulfide in white metal is increasing from iron in the concentrate and as a consequence the copper sulfide percentage is reduced.

In actual operation, changing of oxygen or blowing air flow rate cause major changes in the %Cu in white metal. The significance of oxygen enrichment can not be described from this model because of the different standard condition. For further study, it should have analysis of changing standard condition together with this study.

The effects of oxygen flow rate on the bath temperature are shown in Figure 5-7 (e). The temperature is decreasing when flow of oxygen is increased because in the assumptions, the oxygen flowrate of 7,000 Nm^3/hr is enough to react with concentrate and the additional increase of oxygen will not proceed in further reactions. Heat is loss to the environments or to heat up from ambient to the bath temperature.

It can be seen from figure 5-7 (f) that 35%Fe in copper concentrate has resulted in the highest yield in PSR. Even through this concentrate have the lowest %copper in white metal and the lowest copper content in slag, it has also the highest yield. The yield is varied depend on the quantity of white metal and slag.

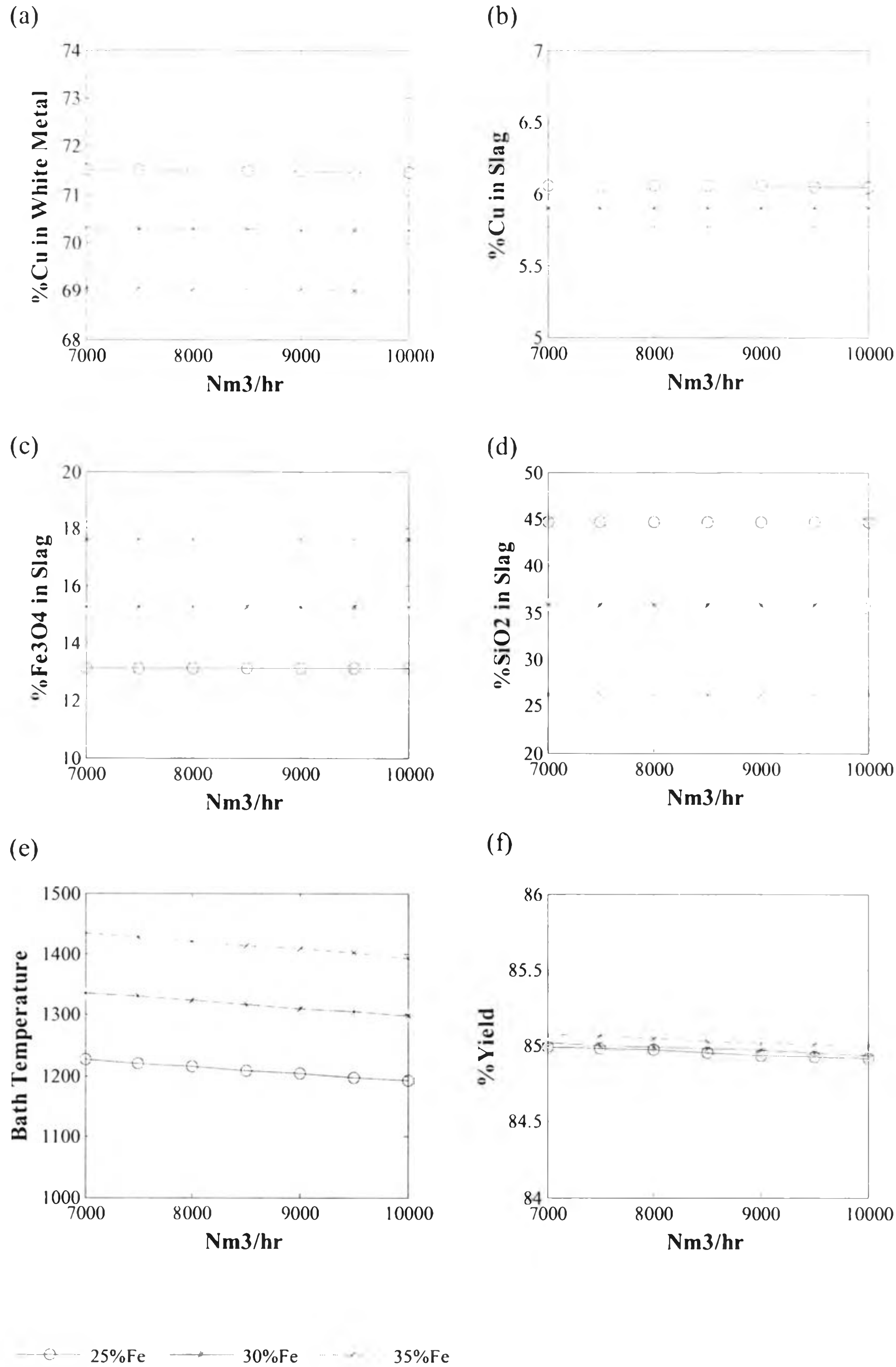

Figure 5-7 (a) – (f): Variation of industrial oxygen flow rate and %Fe in copper concentrate

5.2.3 Effect of blowing air flow rate

There is no variation in the composition of white metal and slag caused by increasing of blowing air flow rate as shown in the trends in Figure 5-8 (a) to (d). This is mainly because of the limitation of copper and iron content in concentrate which is the same amount for constant concentrate feed rate. The model has limitation from fixing extent of reaction and does not include thermodynamic consideration so that it could not include variations in oxygen that could cause the further oxidation of FeS.

In Figure 5-8 (e), the effect of increasing blowing air flow rate on the bath temperature shows a decreasing trend. This is mainly the contribution of the amount of inert nitrogen gas that is required to heat and to rise in the desired temperature.

In comparison with oxygen flow rate, the variation of blowing air flow rate has more effect with the decrease in bath temperature than oxygen flow rate due to the higher amount of inert nitrogen content. However, in this case, the temperature ranges are higher temperature than the case of changing oxygen flow rate because of the different basis. In the simulations for the variation of blowing air flow rate, the calculations are based on 36%enrichment of oxygen.

It is noted that iron content in copper concentrate is also an impact with temperature and is more than the effect of copper content as shown in Figure 5.8 (e). The highest temperature is near 1500^{o}c.

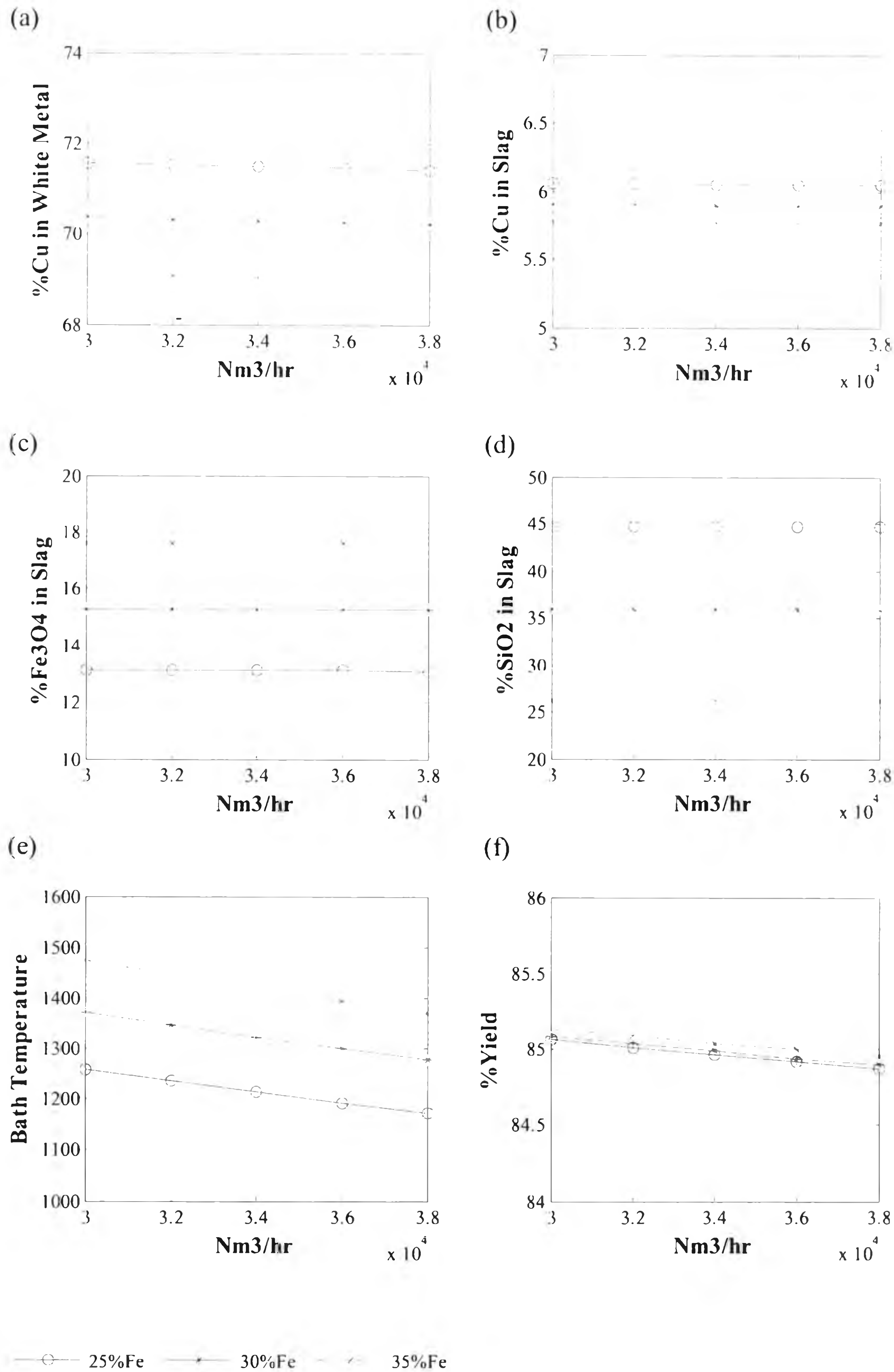

Figure 5-8 (a) – (f): Variation of blowing air flow rate and %Fe in copper concentrate

5.2.4 Effect of flux feed rate

It can be seen from Figure 5-9 (a) that there is no effect on the %Cu in white metal with increases in the feed rate of flux since the silica content in flux react with iron oxide to form slag and has no consequence with white metal composition. Although iron oxide depends on iron sulfide from white metal phase as shown in equation (5-7) but the extent of this reaction was fixed so that if the amount of copper concentrate is not changed, the amount of iron sulfide in white metal is not varied too. Consequently, the 25%Fe in copper concentrate provided the highest %Cu in white metal because it has the lowest iron to produce iron sulfide.

$$FeS\text{ (white metal)} + O_2\text{(gas)} \rightarrow FeO\text{(slag)} + SO_2\text{(gas)} \qquad \textbf{(5-7)}$$

The %Cu in slag decrease with increasing flux feed rate because the amount of slag increases with the addition of silica and the quantity of white metal that distribute to slag phase is still the same hence that the proportion of copper in slag is lessen.

From Figure 5-9 (c) and 5-9 (e) shows the flux feed rate below 4 tph for 25%Fe in concentrate has high temperature and magnetite due to the high magnetite forming reaction which consume heat to generate magnetite. This reaction happens because of the silica not enough to form fayalite slag and the remaining FeO is over oxidized and forms Fe_3O_4. The silica in excess goes to the slag phase hence the percentage of silica in slag is higher consequently.

It is noted that $\%SiO_2$ in slag is included with fayalite slag ($2FeO.SiO_2$ or Fe_2SiO_4) and free silica so that in Figure 5-9 (d), the figure in percentage shows both of these materials.

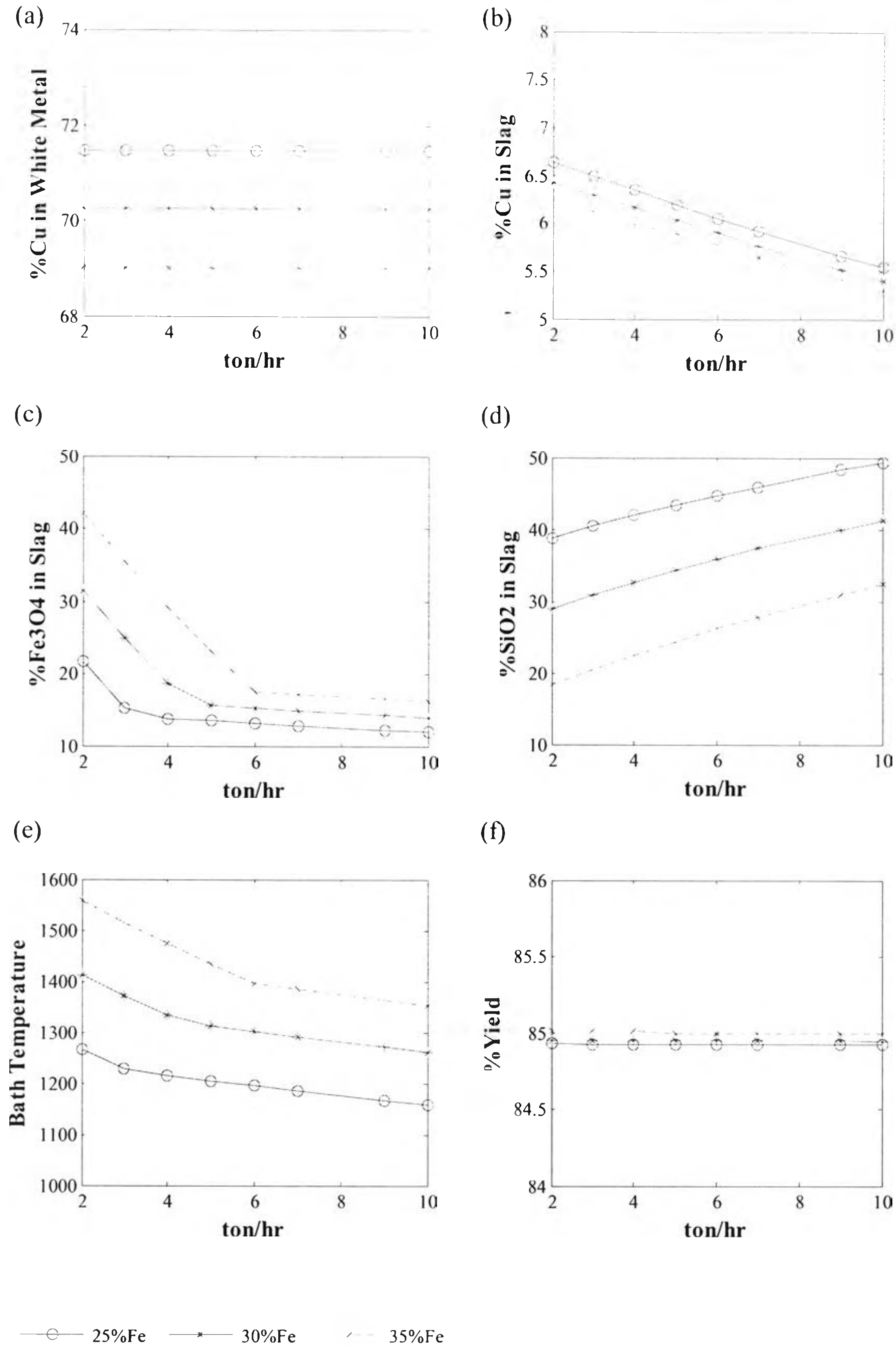

Figure 5-9 (a) – (f): Variation of silica flux feed rate and %Fe in copper concentrate

5.2.5 Effect of revert feed rate

It can be seen from Figure 5-10 (a) that %Cu in white metal shows an increasing trend as revert feed rate increases consistent with equation (5-3) and (5-4) . The low iron content in concentrate which produced low copper grade in white metal can be improved by adding revert provided the PSR temperature is also taken into consideration.

The Figure 5-10 (e) show that bath temperature trend decreases with increasing the feed rate of revert consistent with the amount of heat required to melt the additional reverts. It is noted in normal operations, the adjustment of revert feed rate is used for control the bath temperature when it has higher than 1250°C. If the temperature is not beyond this point, the reverts addition needs to be controlled. Also, the model simulated on a daily operation so that 2 to tph of revert is equal to 48 ton per day. Using this as a guide reverts addition of 48 tons a day or 2 tph could cause a temperature drop of 25C.

For PSR yield, the results are shown in Figure 5-6 (f), 5-7 (f), 5-8 (f), 5-9 (f) and 5-10 (f). These all indicate that revert addition has the most important effect to PSR yield. However, the yield varies under different controlled parameters such as %Cu in white metal so that the optimum %Cu in white metal should investigated to get the good process results and high yield.

In conclusion, the iron content in copper concentrate should be controlled in range which is not more than 1% because from the result of simulation, the slag quality such as $\%SiO_2$ and $\%Fe_3O_4$ can be significantly affected (5% change in iron content affects $\%SiO_2$ in slag by about 10%) and this will effect the control of the process.

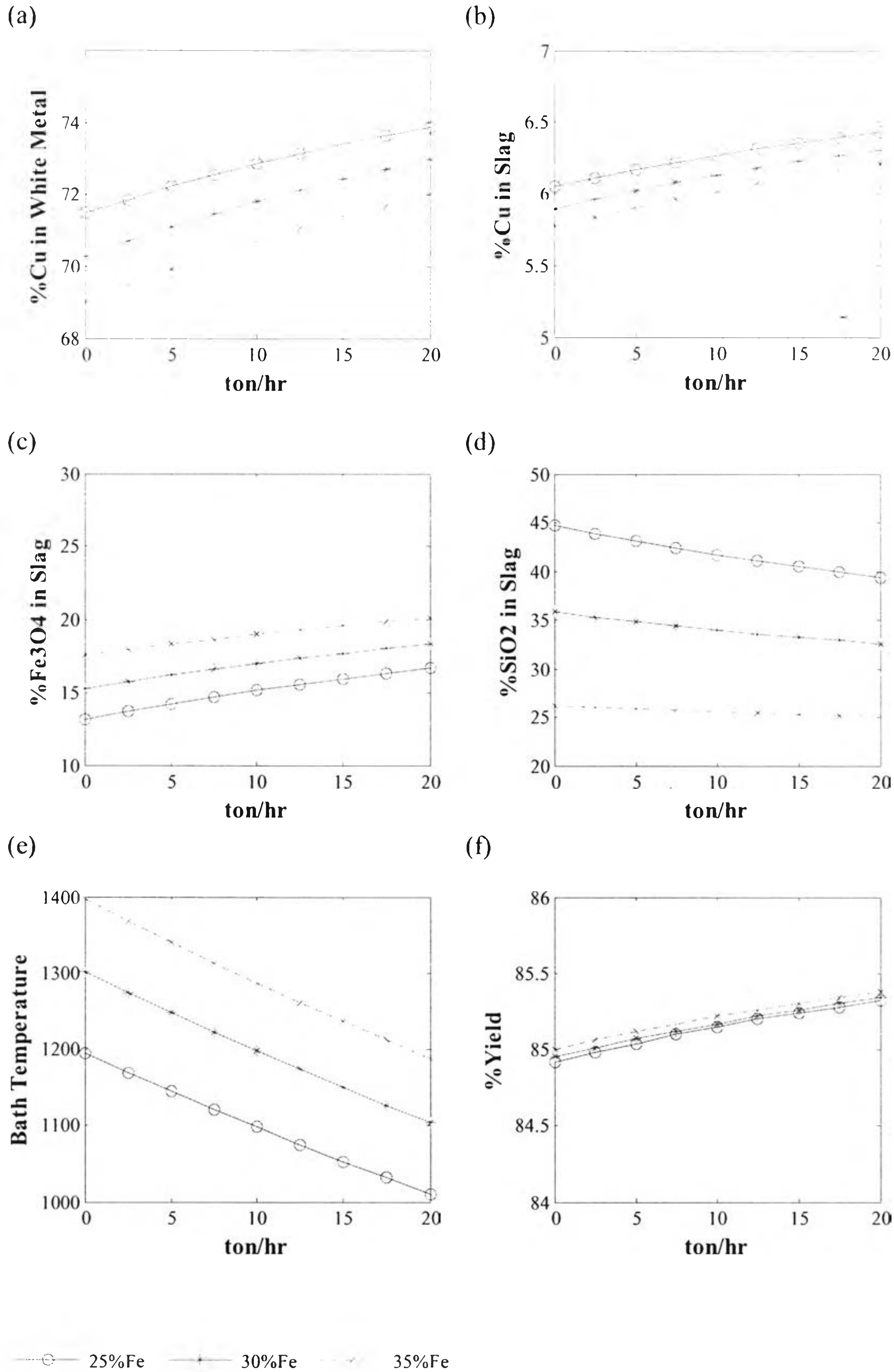

Figure 5-10 (a) – (f): Variation of revert feed rate and %Fe in copper concentrate

5.3 Variation of sulfur in copper concentrate

Sulfur content in copper concentrate is also another important parameter that needs to analyze because of its impact on the energy balance to the PSR. For this reason, the investigation on the sulfur variation based on Table 5-1, where copper concentrates containing 25%, 30% and 35% sulfur were simulated. It is noted that sulfur chemical composition is changed by 5% but the mineralogical composition in these computations maintained that the highest value is chalcopyrite with a composition of 30%S in concentrate.

5.3.1 Effect of concentrate feed rate

The trends in Figure 5-11 (a) show that the %Cu in white metal is almost the same value with the increase in concentrate feed rate and %sulfur in concentrate. It is attributed to the assumption in Table 5-1 where copper and iron content are the same so that iron sulfide was produced is also the same. However, at the feed rate of more than 70 tph of concentrate and containing 35%sulfur, the trend in %Cu in white metal reduced significantly. This is because the oxygen is not enough to react with FeS to produce FeO to slag phase and the FeS remaining in white metal is high.

The copper content in slag tend to increase with increasing feed rate as shown in Figure 5-11 (b) mainly from the higher %Cu in the white metal that distribute into slag phase.

The amount of Fe_3O_4 increases with increasing concentrate feed rate and higher sulfur composition in dry concentrate as shown in Figure 5-11 (c) because the slag production is increasing. On the other hand, the amount of SiO_2 is decreasing because the amount of FeO in slag and slag forming reaction also occurs more. The effect of %S in concentrate on the %SiO_2 as shown in Figure 5-11 (d) shows that the concentrate with 25%sulfur content have highest %SiO_2 in slag. Again, this is based of the assumption that gangue composition which remain in the concentrate is represented mainly by silica so that with less copper, there are more silica that does not react as the natural silica.

The effect of increasing concentrate feed rate and %S in concentrate related to the bath temperature shows an increasing trend as seen in Figure 5-11 (e) because of net heat generated by the copper concentratc is increasing from the pyritic sulfur combustion.

Consistently, the results with the 25%S in concentrate also show the lowest magnetite and copper content in slag. These effects come from total composition in copper concentrate as seen from Table 5-1 where total mineral composition in each concentrate is different about 5% and the residue is assume to be gangue. The concentrate with 25%S contains the biggest amount of gangue. Consequently, PSR temperature will be lower due to the heat required for melting gangue as seen in the Figure 5-11 (e). For this discussion, the effect copper concentrate feed rate is most significant to the bath temperature as shown in Figure 5-11 (f) due to the heat generation. Increasing concentrate feed rate with increasing the sulfur content shows increasing bath temperature and yield.

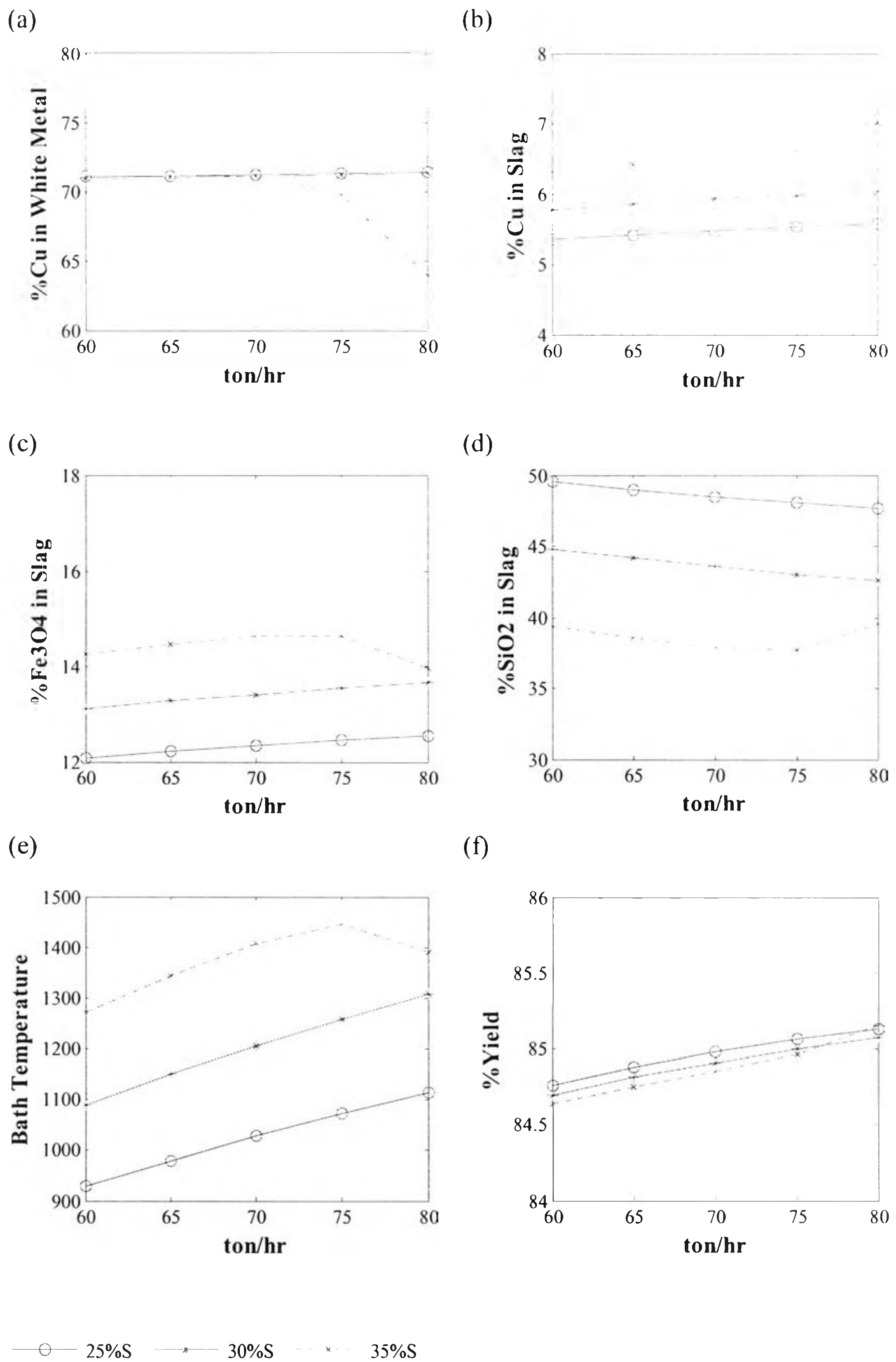

Figure 5-11 (a) – (f): Variation of Copper Concentrate Feed Rate and %S in Copper Concentrate

5.3.2 Effect of industrial oxygen flow rate

Changing oxygen flow rate is no effect with copper in white metal due to the same reason given in topic 5.3.1 and for the cases where oxygen is not enough to oxidized FeS as shown in equation (5-8). Figure 5-12 (a) shows that oxygen flow rate of less than 9,000 Nm^3/hr and 35%sulfur in concentrate does not have enough oxygen for the oxidation reactions and thus will produce low copper grade.

$$2FeS + O_2 \rightarrow 2FeO + S_2 \qquad \textbf{(5-8)}$$

The effect of changing oxygen flow rate is no variation in slag quality because of the constant amount of copper and iron from the same copper concentrate feed rate. However, in the case of 35% sulfur in copper concentrate where there is not enough oxygen, these results in lower FeO, lower magnetite and higher copper in slag as illustrated in Figure 5-12 (b), (c) and (d).

The temperature of PSR tend to decrease when oxygen flow rate is increased because for the same concentrate flow rate causes no additional oxidizing reactions for FeS and hence no additional heat generated to the reactor.

5.3.3 Effect of blowing air flow rate

There is no variation in the composition of white metal and slag cause by increasing of blowing air flow rate because of the limitation on the copper and iron content in concentrate which is the same amount for constant concentrate feed rate as shown in Figure 5-13 (a) to (d).

The effect of increasing blowing air flow rate decreases the bath temperature as seen in the trends in Figure 5-13 (e) because of amount of inert nitrogen gas which is required to heat and to rise in temperature.

In comparison with effects of oxygen flow rate, the effect of blowing air flow rate is more significant on the bath temperature than oxygen flow rate due to the higher amount of inert nitrogen gas to be heated up.

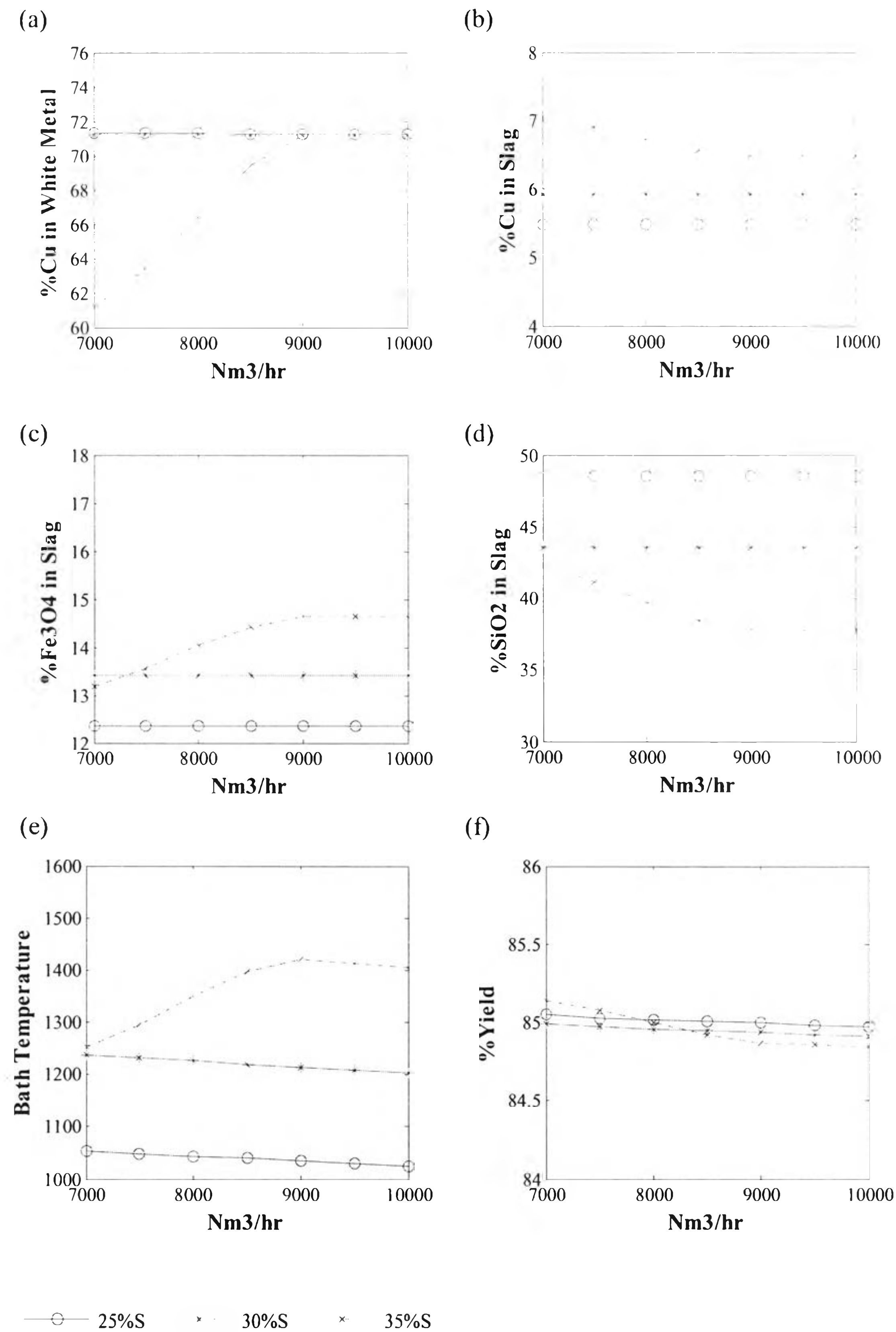

Figure 5-12 (a) – (f): Variation of industrial oxygen flow rate and %S in copper concentrate

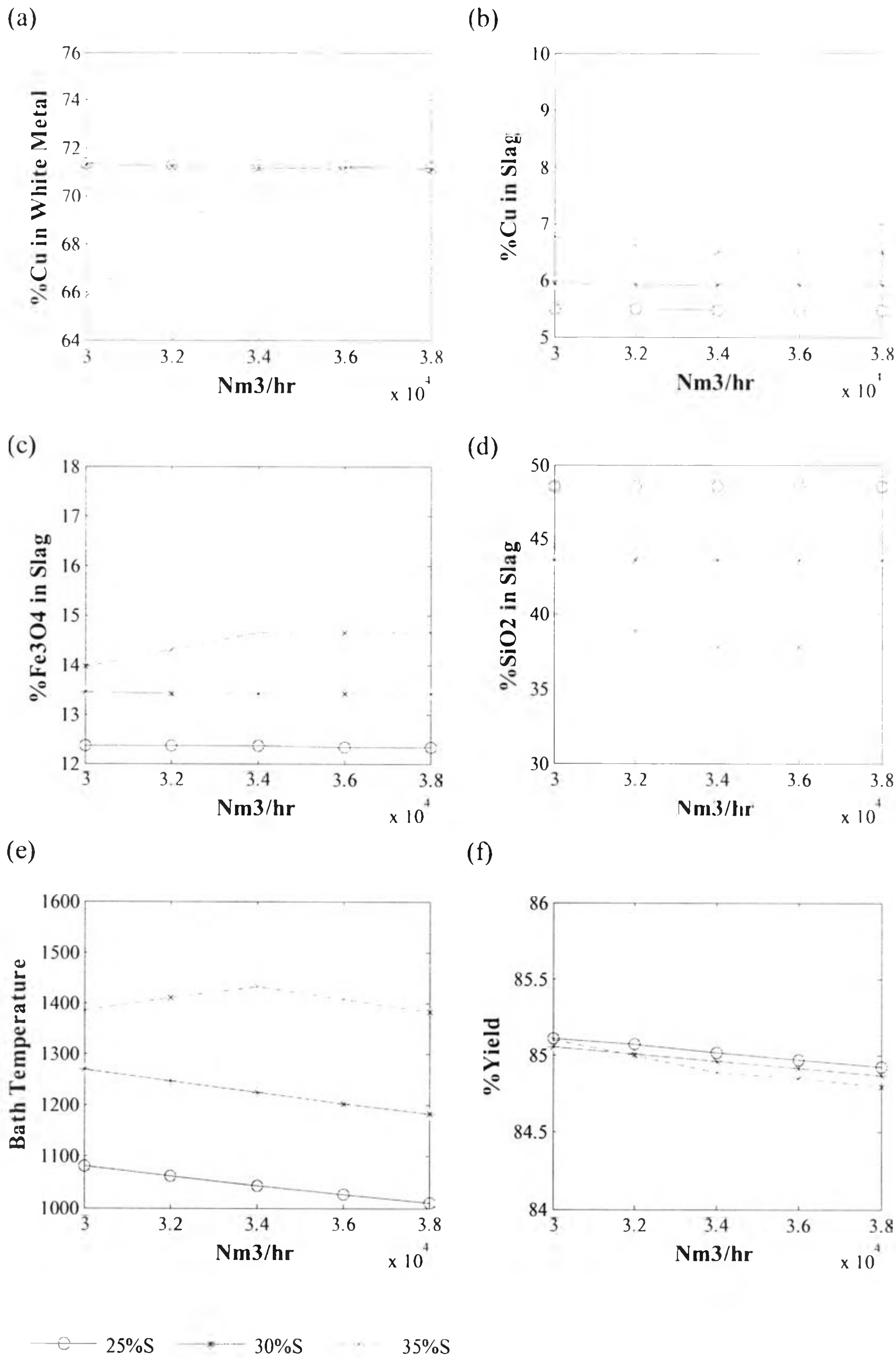

Figure 5-13 (a) – (f): Variation of blowing air flow rate and %S in copper concentrate

5.3.4 Effect of flux feed rate

It can be seen from the trends in Figure 5-14 (a) that there is no effect with %Cu in white metal with increases in the feed rate of flux since the content of silica in flux react with iron sulfide to form slag and has no consequence with white metal composition.

The effect of flux addition on the copper in slag is illustrated in Figure 5-14 (b). The %Cu in slag shows decreasing trend with increasing flux feed rate because of the amount of slag increases from the addition of silica while the quantity of white metal that distribute to slag phase remains the same so that the proportion of copper in slag is lessen.

From the trends in Figure 5-14 (c) and 5-14 (e) shows that flux feed rate below 4 tph has high temperature and magnetite due to the high magnetite forming reaction which consume heat to generate magnetite. This reaction occurs because the silica is not enough to form fayalite slag and the remaining FeO is over oxidized to form Fe_3O_4. In the opposite way, the additional silica in excess goes to the slag phase and results in higher silica content in the slag.

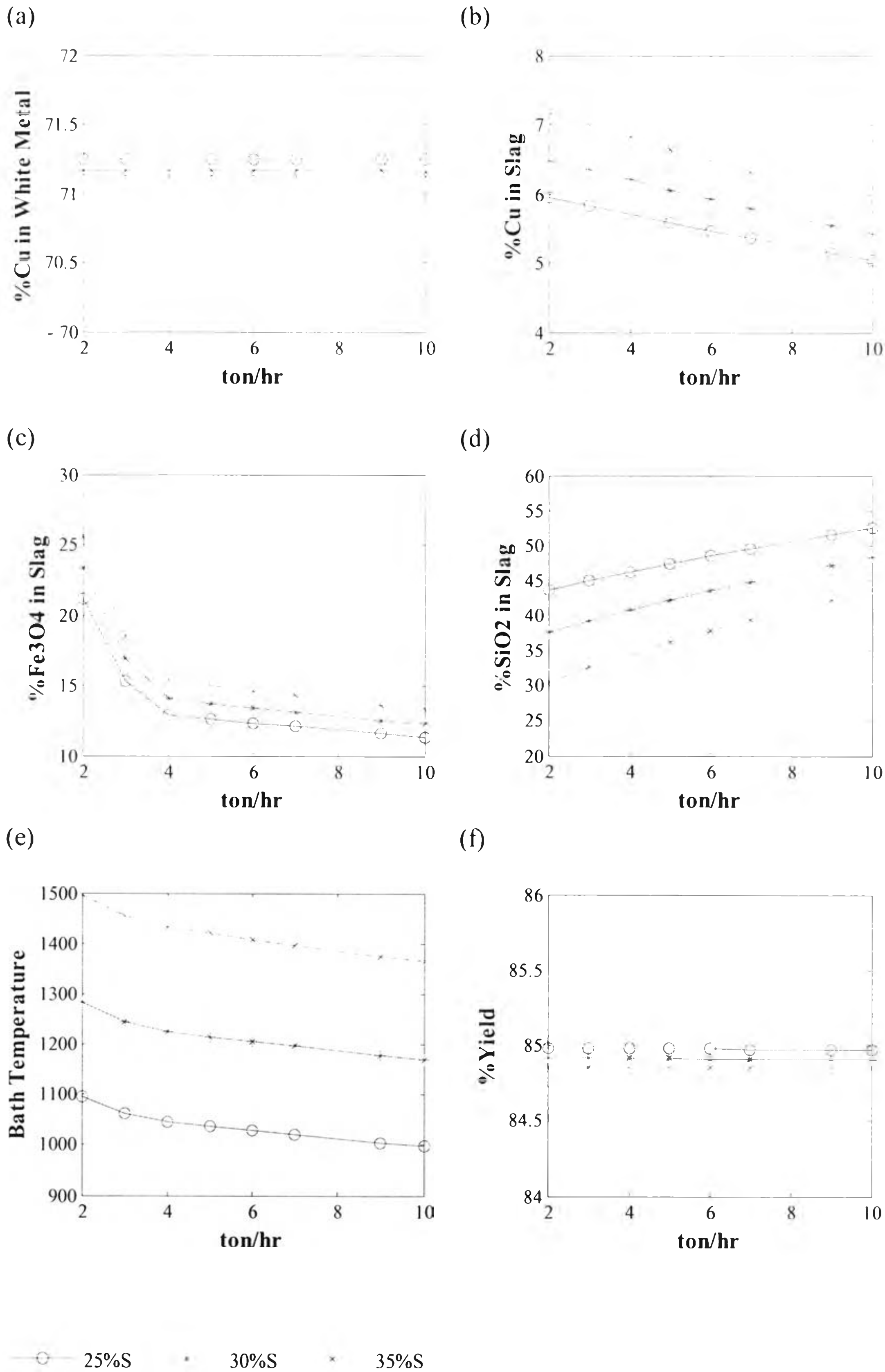

Figure 5-14 (a) – (f): Variation of silica flux feed rate and %S in copper concentrate

5.3.5 Effect of revert feed rate

The results of variation in revert feed rate were shown in Figure 5-15 (a) to (f). The %Cu in white metal shows an increasing trend increasing with increasing revert addition because copper contents in revert is recovered when they are melted. The effect of the differences in %S content in the copper concentrate is not related with %Cu in white metal because the copper and iron content is still the same amount. However, the trend copper content in slag as seen in Figure 5-15 (b) is also increasing from the melting copper oxide contained in revert. In order to compare that copper which is recovered in white metal is more than copper which is loss to slag phase, Figure 5-15 (f) shows that the yield is increasing indicating copper is in the reverts is recovered

It can be seen from the trends in Figure 5-15 (c) that magnetite content in slag is increasing because the reverts contain magnetite. In Figure 5-15 (d), the silica content in slag is decreasing because the revert contains iron sulfide and promotes the slag forming reaction.

Figure 5-15 (e) trends show that temperature decreases with increasing revert feed rate because of the additional materials that require heat to melt.

5.4 Operation guideline

The objective of the copper concentrate and process variables analysis is to provide better understanding of the adjusted variables and controlled variables for every copper concentrate blend for the control room operator. It is expected that the method to control the reactor is based on the calculation sheet for the operator to adjust the process variables efficiently. An example of calculation sheet is shown in Figure 5-16. It consists of two main subjects, the first subject is the blending formula shown for copper concentrate and revert properties. The second is the smelting parameters showing the value for controlled process parameter.

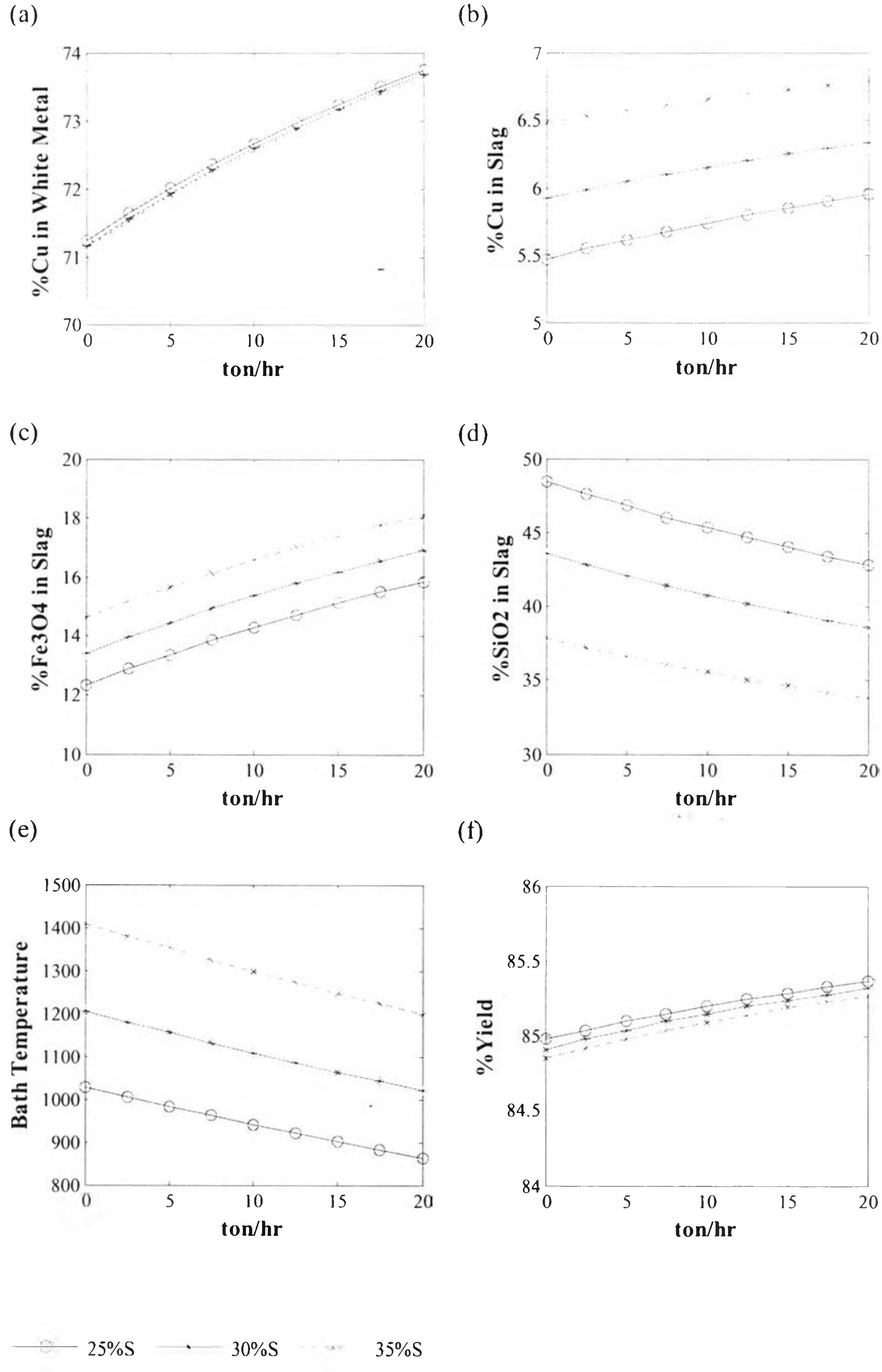

Figure 5-15 (a) – (f): Variation of revert feed rate and %S in copper concentrate

The calculation sheet is taken from METSIM model. It can be used for simulating copper concentrate properties by calculating the amount of oxygen and silica flux requirement of each concentrate blending. The second part is useful for the adjustments and control for a stable operation.

Concentrate Blending Formula

Blending no. ________________
Concentrate 1 ________________
Concentrate 2 ________________
Concentrate 3 ________________

Properties	Unit	Blending
Cu	%	
Fe	%	
S	%	
SiO_2	%	

Revert lot no.___

Calculation Propeties

Flux consumption/ton		
Oxygen consumption/ton		
White metal/ton		
Slag/ton		

Smelting Parameter

Adjusted variables	Unit	Normal case			Case 1		Case 2		Case 3		Case 4	
Dry Conc. feed rate	tph	70	75	80	75	75	75	75			75	75
Revert feed rate	tph	0	2	4	***0***	***4***	2	2	2	2		
Silica flux feed rate	tph	6	7	8	7	7	***6***	***8***	7	7	7	7
Oxygen flow rate	Nm^3/hr	8000	8500	9000					8500	8500	8500	8500
Controlled variables												
PSR temperature	^oC	1250	1250	1250							***1200***	***1300***
%Cu in white metal	%	72	72	72					***70***	***74***		
%Fe_3O_4 in slag	%	18	18	18								
%SiO_2 in slag	%	24	24	24								

Remark
case 1 : Adjust revert feed rate
case 2 : Adjust flux feed rate
case 3 : Change in copper grade
case 4 : Change in temperature

Figure 5-16: Calculation sheet for control PSR reactor