Surface Tension and Wettability Studies of Liquid Fe-Ni-O Alloys

A. SHARAN and A.W. CRAMB

Surface tensions of iron-nickel alloys were measured as a function of oxygen potential at 1550 °C using the sessile drop technique. The surface tension of pure liquid nickel and iron-nickel alloys was measured at a total pressure of 1 atmosphere under varying CO_2/CO ratios. An increase in the oxygen potential in the gas phase was found to correspond to a decrease in surface tension of pure nickel and iron-nickel alloys, indicating that oxygen is surface active in both liquid nickel and iron-nickel alloys. At low oxygen potentials, nickel additions to liquid iron were found to cause small decreases in alloy surface tensions; however, at higher oxygen potentials, the surface tension of the alloy exhibited a minimum value as nickel was added to iron. The adsorption coefficients of oxygen in liquid iron-nickel alloys and pure liquid nickel were determined from the surface-tension data using Belton's analysis, and were found to be similar to those calculated from kinetic studies. Wettability of iron-nickel alloys on an alumina substrate was studied through contact-angle measurements. At a constant alloy nickel content, the contact angle between the alloy and alumina decreased with increased oxygen potential in the gas phase.

I. INTRODUCTION

A knowledge of the surface tension of liquid iron-based alloys is important in understanding the processing of liquid steel. Phenomena such as nitrogen adsorption and slag emulsification can be related to the surface energies of liquid steels. To better understand the processing of stainless steels and iron-nickel alloys, an understanding of the surface tension of iron-nickel alloys is necessary. Oxygen contamination of steels has been known to be a major problem in steel processing. There have been numerous studies of the effect of oxygen on the surface tension of pure iron, and only a few studies on the effect of oxygen on pure liquid nickel; however, there have been no published studies of the effect of oxygen on the surface tension of ternary iron-nickel-oxygen alloys.[1] In the present work, the surface tension of liquid iron-nickel alloys and of pure liquid nickel was measured at 1550 °C under varying oxygen potentials using samples of high purity and modern image-processing techniques. Contact angles of liquid iron-nickel alloys on solid alumina substrates were also determined at different oxygen levels.

II. EXPERIMENTAL TECHNIQUE

The sessile drop technique was used to measure the surface tensions of liquid iron-nickel alloys in gas mixtures of carbon dioxide and carbon monoxide at 1550 °C. A SiC resistance furnace was used in combination with an X-ray radiographic unit for these experiments (Figure 1). The vertical reaction tube, which was made of high-purity alumina, was open at both ends. The tube was hermetically sealed by means of O-rings fitted onto aluminum water-cooled jackets, which were placed at the two ends of the tube. The alumina furnace tube was 42-in. long and had an outer diameter of 4 in. and an inner diameter of 3-5/8 in. The solid metal samples were placed in a conical alumina crucible (McDanel (McDanel, Refractory, Beaver, PA) 998 high-purity alumina, 22-mm top diameter, 33-mm height). The arithmetic mean roughness of the alumina substrate within the crucible was measured to be 0.86 μm. The Fe-75 wt pct Ni and pure nickel samples were placed in magnesia crucibles of the same dimensions, since pure liquid nickel was found to react with alumina, causing gas evolution within the droplet. The crucible was placed into the furnace tube at 1400 °C on top of a pedestal, which consisted of sintered alumina powder contained in a shallow alumina dish. The experiments were performed in a reducing atmosphere of a CO_2-CO gas mixture (premixed in gas cylinders) and the oxygen potential of the system was set by the P_{CO_2}/P_{CO} ratio of the gas atmosphere. The gas flow rate through the furnace tube was about 500 mL/min. After the crucible was placed on the alumina pedestal, the temperature of the furnace was raised to 1550 °C.

At least four X-ray pictures of each metal droplet were taken at intervals of 30 minutes. The picture of the liquid metal droplet was printed on KODAK* Polycontrast IIIRC paper, with a magnification factor of about 25. The picture of the droplet was scanned (using a 300-dpi Sharp JX-320 scanner) and the image was then stored in a MACINTOSH** fx, where the droplet image was treated for edge detection using Image software (Research Services, National Institute of Health, Bethesda, MD). The coordinates of the edge of the droplet were determined using Hypercard

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A. SHARAN, formerly Graduate Student, Department of Materials Science and Engineering, Carnegie Mellon University, is Research Engineer with Homer Research Laboratory, Bethlehem Steel Corporation, Bethlehem, PA 18016. A.W. CRAMB, Professor, is with the Department of Materials Science and Engineering, Carnegie Mellon University, Pittsburgh, PA 15213.

Manuscript submitted August 11, 1995.

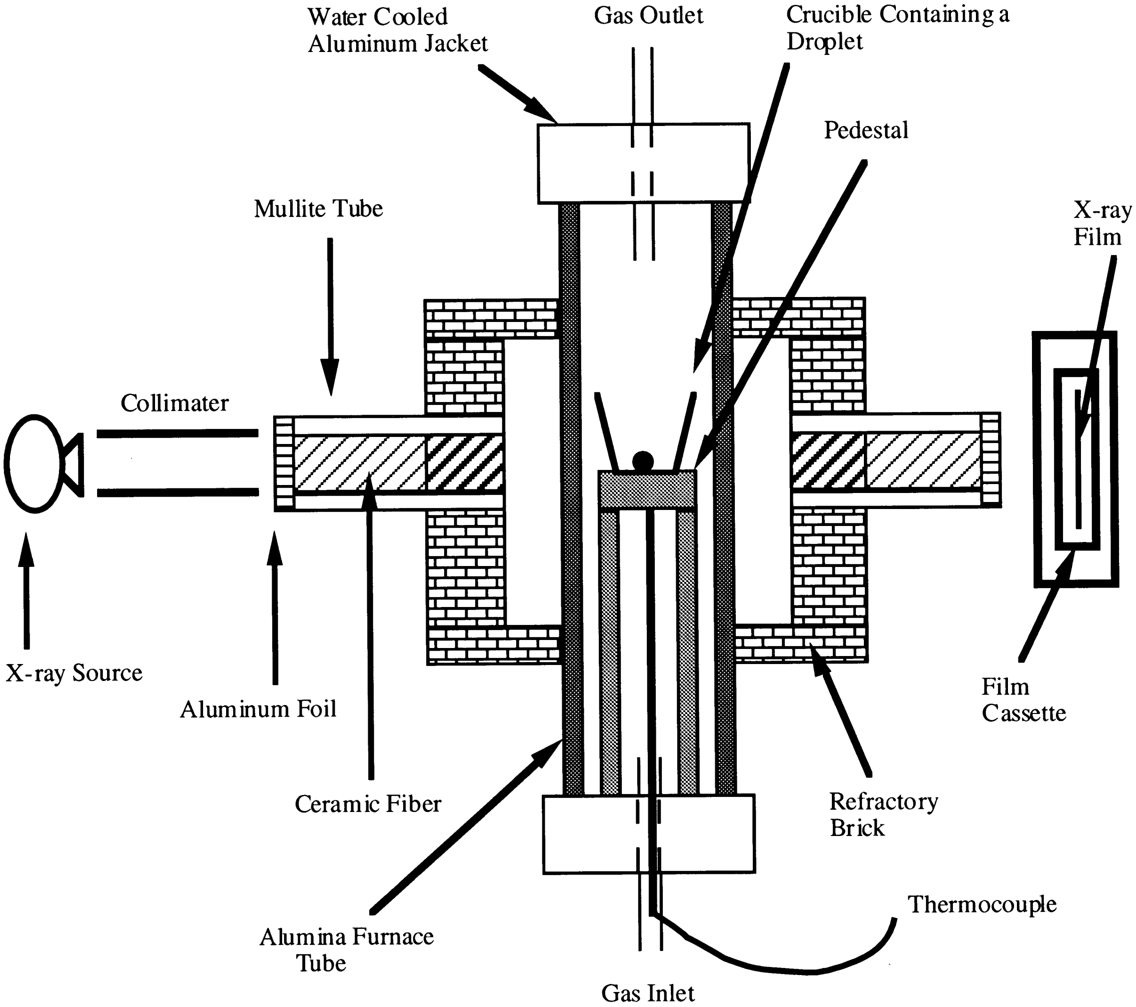

Fig. 1—Schematic of experimental apparatus.

software (Apple Computers Inc., Cupertino, CA), which were then transferred to a computer program developed by Rotenberg *et al.*[2] that numerically integrates the Young–Laplace equation to determine the surface tension between the liquid metal and the gas atmosphere. A detailed account of the experimental setup and the computational technique is provided in References 2 through 6.

The iron-nickel alloys were prepared by melting measured quantities of solid iron (99.99 pct metallic purity, Noah Technology, San Antonio, TX) and solid nickel (99.995 pct metallic purity, Johnson-Matthey, Ward Hill, MA) in an induction furnace under an Ar-CO atmosphere. The iron-nickel alloys thus prepared were chemically analyzed for sulfur, and were found to contain less than 10 ppm of that element. Nickel samples were prepared using the solid nickel provided by the suppliers. Conical pieces, each weighing about 1.2 g, were cut from the metal samples. Each conical piece was carefully polished with an abrasive paper and washed with acetone to clean its surface.

Possible sources of error are as follows: (a) nonaxisymmetrical metal droplets, (b) contamination in metal samples, and (c) variation in identification of the position of the metal droplet surface during image processing. The amount of error in the experimental results is difficult to estimate, as it is not possible to express surface tension as an explicit mathematical function of these variables. However, extreme care was taken to minimize error from each of these sources. For each experiment, droplet pictures were processed at least 12 times and an average of the results from each of these pictures were taken. Each experiment was performed several times, and more than 50 pct of the measurements were found to be within ±5 pct of the mean value.

III. RESULTS

Sessile drop experiments were performed over the entire composition range of the iron-nickel system. The surface-tension results obtained for Fe-Ni alloys at 1550 °C under different P_{CO_2}/P_{CO} ratios are presented in Table I.

A group of experiments was carried out at 1550 °C under an atmosphere of 0.1 pct CO_2-balance CO gas mixture. The partial pressure of oxygen in this atmosphere was calculated to be 7.7×10^{-14} atm. The equilibrium oxygen content of iron-nickel alloys corresponding to this gas composition was calculated, using the free energy of dissolution values determined by Ichinose,[7] to be less than 10 ppm.

A. *Surface Tensions of Liquid Iron and Nickel*

The surface tension of pure liquid iron under the aforementioned conditions was determined to be 1870 mN/m,

Table I. Surface Tensions of Fe-Ni Alloys at 1550 °C under Gas Atmospheres with Different P_{CO_2}/P_{CO} Ratios

PCO$_2$/PCO Wt Pct Ni	0.001	0.01	0.047	0.081	1.0	10.0	30.0
0	1870	—	—	—	—	—	—
5	1830	—	—	1180	—	—	—
10	1830	1700	1240	1140	—	—	—
15	1810	—	—	1100	—	—	—
20	1780	1510	1200	1220	—	—	—
30	1800	—	—	1460	—	—	—
40	1780	1750	1710	1730	—	—	—
75	1700	—	—	—	—	—	—
100	1800	—	—	1730	1490	1380	1230

Table II. Surface Tension of Liquid Nickel at Different Temperatures

Reference	Surface Tension of Liquid Nickel (mN/m)	Temperature (°C)
Present work	1800	1550
Kozakevitch and Urbain[10]	1924	1550
Kingery and Humenik[11]	1570	1470
Fraser *et al.*[12]	1998	1550
Keene *et al.*[13]	1769	1550
Popel *et al.*[14]	1735	1550
Minaev *et al.*[16]	1680*	1550
Lee *et al.*[15]	1792	1550
Monma and Suto[17]	1620*	1600
Eckler *et al.*[18]	1924	1455

*Surface tension values estimated from plots.

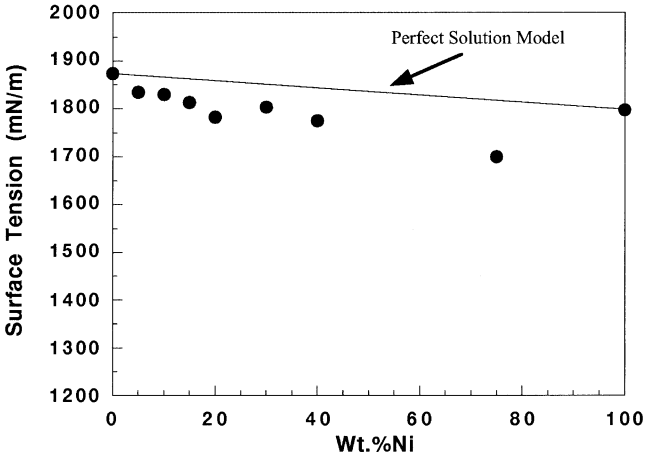

Fig. 2—Effect of nickel on the surface tension of iron-nickel alloys at a low oxygen partial pressure (P_{CO_2}/P_{CO} = 0.001).

while that of pure liquid nickel was found to be 1800 mN/m. The surface tension of liquid iron has been found to be approximately 1900 mN/m by a number of investigators in the past,[8,9,10] which is very close to the value determined in the present study. Table II, which lists the surface tensions of liquid nickel measured in the past,[10–18] illustrates the disagreement among previous researchers. The present data for pure nickel are in reasonable agreement with those of Keene *et al.*,[13] Popel *et al.*,[14] and Lee *et al.*[15] but is substantially lower than the value determined by Fraser *et al.*[12]

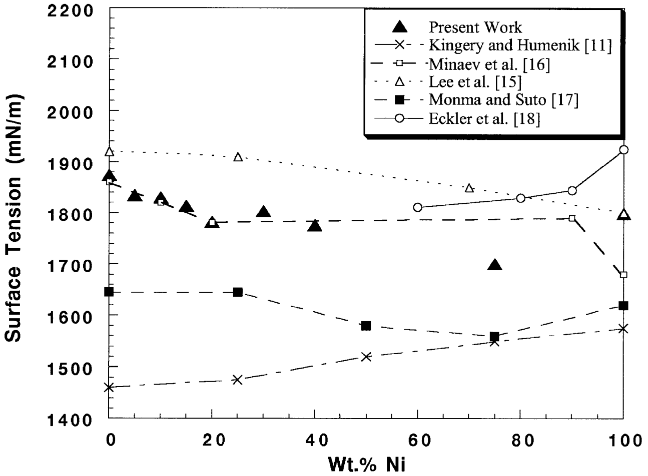

Fig. 3—A comparison between present and previous work on the effect of nickel on surface tension of iron-nickel alloys.

B. *Surface Tensions of Liquid Iron-Nickel Alloys at Low Oxygen Potential*

The surface tensions determined for iron-nickel alloys at a ratio of P_{CO_2}/P_{CO} = 0.001 are shown in Figure 2. Results indicate that nickel additions to iron cause small decreases in the alloy surface tension at low oxygen potentials.

A comparison of the surface tensions of iron-nickel alloys determined in this study with the results of previous investigators is given in Figure 3.[11,15–18] The iron-nickel surface-tension results from the present work are in reasonable agreement with those of Lee *et al.*[15] and Minaev *et al.*[16] There is, however, a substantial disagreement between the present results and those of Kingery and Humenik[11] and Monma and Suto.[17] The results obtained by Eckler *et al.*[18] in the higher nickel range are greater than the surface tensions determined in the present study in the same range, by about 100 mN/m. Most of the previous studies were carried out under ill-defined oxygen potentials. The variation in the past data could be attributable to (a) varying levels of oxygen or sulfur present during experiments in the iron-nickel samples used in the previous studies, (b) variations in experimental technique, and (c) variations in temperature.

C. *Surface Tensions of Liquid Nickel and Iron-Nickel Alloys as a Function of Oxygen Potential*

The surface tension of liquid nickel was measured at varying oxygen potentials by varying the P_{CO_2}/P_{CO} ratio from 0.001 to 30 at 1550 °C. The results from the present work are plotted in Figure 4, where the surface tension of liquid nickel decreases with increases in oxygen potential in the gas phase. The results from the present work appear to be in good agreement with those of Ogino and Taimatsu[19] and Eremenko and Neidich[20] at low oxygen potentials (Figure 5). However, at higher oxygen potentials, the surface tensions were found to be higher than the trends suggested from the results of the previous two studies.

Figure 6 shows the variation of the surface tension of liquid Fe-10 wt pct Ni alloy at 1550 °C as a function of the P_{CO_2}/P_{CO} ratio in the gas atmosphere. Also plotted in the figure is the surface tension of pure liquid iron deter-

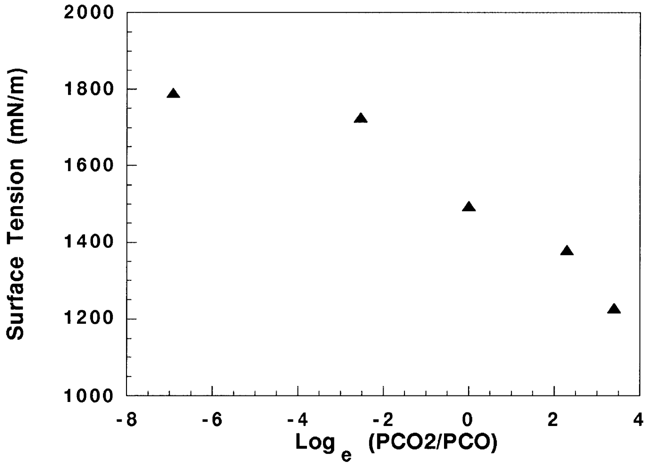

Fig. 4—Effect of increasing oxygen potential in the gas phase on the surface tension of liquid nickel at 1550 °C.

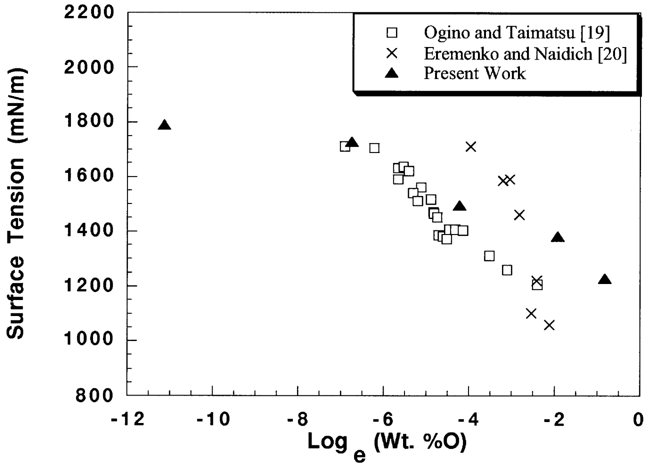

Fig. 5—Comparison between present and previous work on the effect of oxygen on surface tension of liquid nickel.

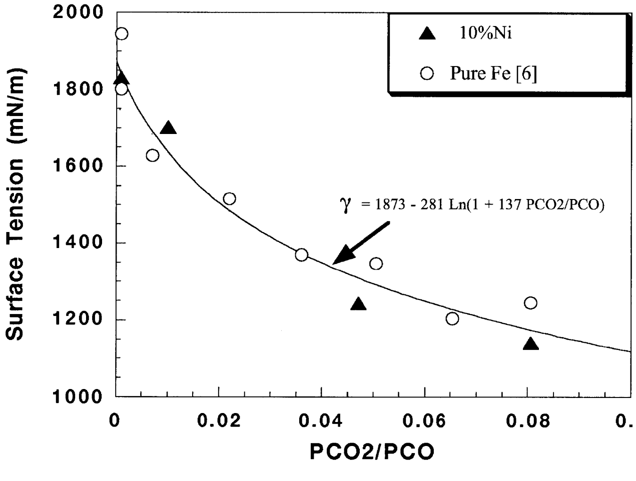

Fig. 6—The effect of oxygen on surface tension of Fe-10 pct nickel alloy.

mined by Jimbo and Cramb.[6] The surface tension of the Fe-10 wt pct Ni alloy appears to be very similar to that of pure iron. The solid line in the figure represents the line of fit through the pure-iron surface-tension data of Jimbo and Cramb,[6] using Belton's equation.[21] Figure 7, which is a plot of the surface tension of the Fe-20wt pct Ni alloy as a function of the P_{CO_2}/P_{CO} ratio in the gas atmosphere, also indicates that the surface tensions of this iron-nickel alloy and pure iron are similar, and follow a similar decreasing trend with increasing oxygen potential. The line of fit using Belton's equation for pure iron is also included in this figure for comparison.

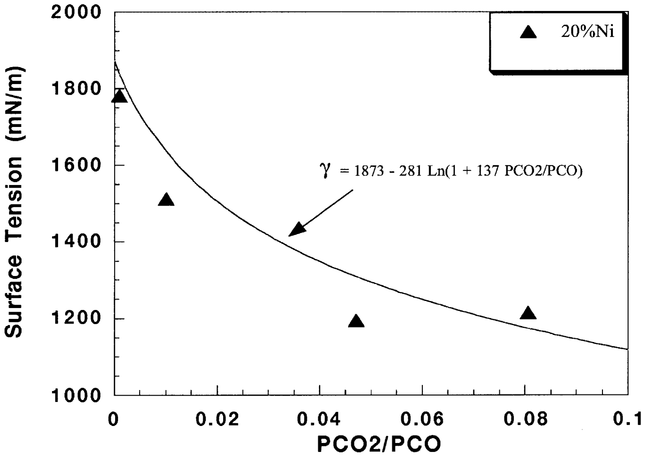

Fig. 7—The effect of oxygen on surface tension of Fe-20 pct nickel alloy.

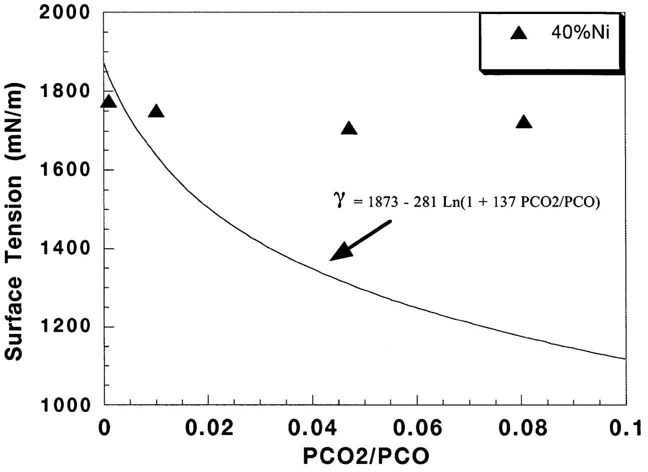

Fig. 8—The effect of oxygen on surface tension of Fe-40 pct nickel alloy.

However, Figure 8, which shows the variation of the surface tension of the Fe-40 wt pct Ni alloy with the P_{CO_2}/P_{CO} ratio, indicates that the decrease in the surface tension of this alloy with increasing oxygen potential is much less than that of pure iron. This indicates that the addition of nickel to the iron-nickel alloy causes an apparent decrease in the surface active behavior of oxygen as the weight percent Ni increases from 20 to 40 pct.

The variation of surface tension of iron-nickel alloys as a function of their nickel contents at varying P_{CO_2}/P_{CO} ratios is shown in Figure 9. The surface tension of the iron-nickel alloy at a low oxygen potential (P_{CO_2}/P_{CO} = 0.001) decreases by a small amount as nickel is added to the alloy. As the P_{CO_2}/P_{CO} ratio in the gas atmosphere increases, the surface tension of the iron-nickel alloys with low nickel contents decreases sharply. For example, the surface tension of the Fe-10 wt pct Ni alloy decreases from 1830 to 1140 mN/m because of P_{CO_2}/P_{CO} ratio increase from 0.001 to 0.081. A similar trend was observed for the Fe-20 wt pct

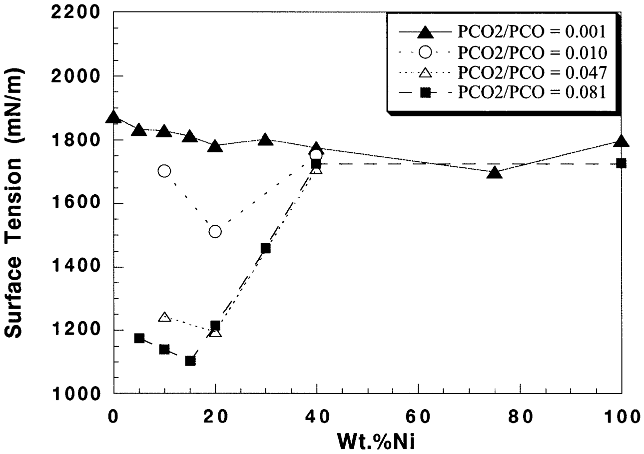

Fig. 9—The effect of nickel on surface tension of Fe-nickel alloys at varying P_{CO_2}/P_{CO} ratios.

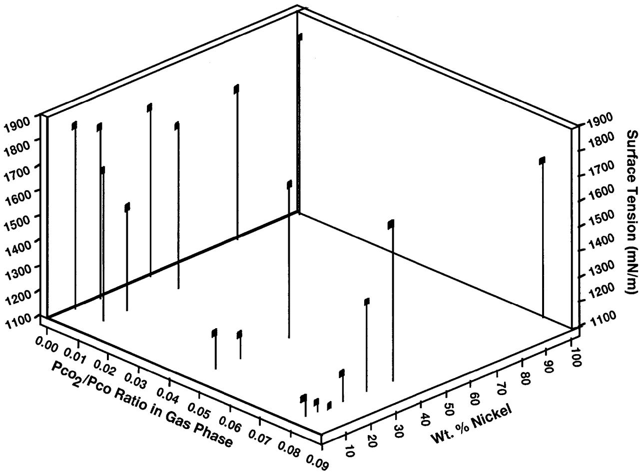

Fig. 10—Three-dimensional plot of surface tension as a function of nickel content and P_{CO_2}/P_{CO} ratio in gas phase.

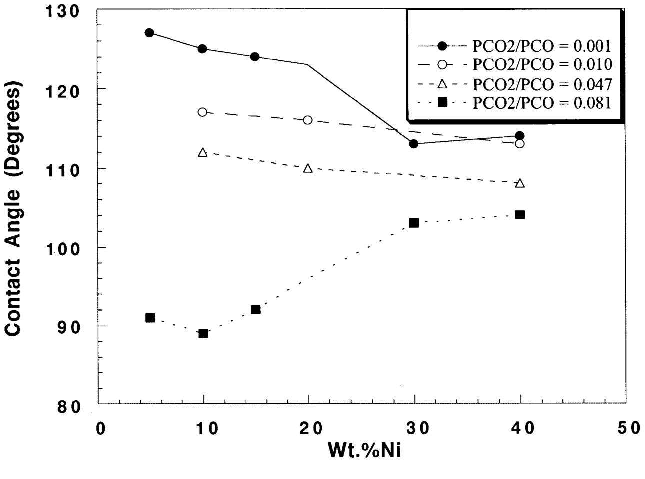

Fig. 11—Variation of contact angle as a function of nickel content and oxygen potential.

Ni composition. However, the effect of oxygen on the surface tension of the alloy was not as prominent in the case of Fe-30 wt pct Ni and reduced further in the case of Fe-40 wt pct Ni alloys.

The surface tension of the alloy increased sharply in the 20 to 40 wt pct Ni range at higher oxygen potentials corresponding to P_{CO_2}/P_{CO} ratios of 0.047 and 0.081. This indicates that there was a significant decrease in the adsorption coefficient of oxygen in the alloy between 20 Ni and 40 wt pct Ni. These surface-tension results are replotted in Figure 10 in three dimensions as a function of P_{CO_2}/P_{CO} ratio in the gas phase and nickel content in the alloy at 1550 °C. In this figure, it can be clearly seen that there is a decrease in the surface tension of the Fe-Ni alloy with an increase in the oxygen potential (P_{CO_2}/P_{CO} ratio) and at the same time, there is a decrease in the surface active nature of oxygen in the alloy with an increase in the nickel content.

D. *Wettability of Iron-Nickel Alloys on Alumina Substrates at Varying Oxygen Potentials*

The contact angles of iron-nickel alloys were measured on alumina substrates at varying oxygen partial pressures in the gas atmosphere (Figure 11). The contact angle of the Fe-5 wt pct Ni alloy at a P_{CO_2}/P_{CO} ratio of 0.001 on alumina was measured to be 127 deg. The contact angle of the alloy decreased to a value of 114 deg at the same P_{CO_2}/P_{CO} ratio as the nickel content of the alloy was increased to 40 wt pct. Contact angles at higher P_{CO_2}/P_{CO} ratios of 0.01 and 0.047 were also found to decrease with nickel additions to the alloy. However, at a P_{CO_2}/P_{CO} ratio of 0.081, the contact angle was found to increase from a value of about 90 to 104 deg with an increase in the nickel content of the alloy from 5 to 40 wt pct.

The results indicate that at low nickel contents, the contact angle of the alloy on alumina shows a large decrease with increasing oxygen potential. The amount of decrease in the contact angle due to an increase in oxygen potential becomes less as the nickel content of the alloy increases. This shows that nickel additions to the alloy reduce the effect of oxygen as a surface/interface active agent and, hence, reduce the effect of oxygen on the contact angle of the alloy. This observation suggests support for an earlier determination of the reduction of the adsorption coefficient of oxygen in the iron-nickel alloy because of nickel additions.

IV. DISCUSSION

A. *Surface Tension of Iron-Nickel Alloys*

The decrease in surface tension of the liquid iron-nickel alloy with nickel additions at low oxygen potentials is attributable to the fact that liquid nickel has a lower surface tension than liquid iron. The following is the surface tension of an ideal *A*-*B* solution, as predicted by the perfect solution model.[22]

$$\exp(-\gamma_{AB}\alpha/\mathrm{R}T) = X_A \exp(-\gamma_A\alpha/\mathrm{R}T) + X_B \exp(-\gamma_B\alpha/\mathrm{R}T) \qquad [1]$$

where γ is the surface tension, X is the mole fraction, R is the universal gas constant, and T is the absolute temperature. The term α is the molar surface area of components *A* and *B* in the monolayer, given by the following relationship:

$$\alpha = \left(\frac{1}{0.918}\right)(N_0)^{1/3}(V_M)^{2/3} \qquad [2]$$

where N_0 is Avogadro's number and V_m is the molar volume of the solution.

A comparison of the surface tension of liquid iron-nickel alloys using the perfect solution model with the experimentally determined data of the present work is shown in Figure 2. The experimentally determined surface tensions of the alloy are slightly lower than the values predicted using the perfect solution model. This is in part attributable to the fact that the iron-nickel system is not ideal and exhibits a negative deviation from Raoult's law.[23] The presence of the third element, oxygen, although present in a very small quantity, can also introduce nonidealities to the behavior of the iron-nickel alloy surface.

B. *Surface Tension of the Liquid Fe-O System*

The surface tension of pure liquid iron has been measured as a function of oxygen potential by a number of investigators in the past.[5,24,25] Oxygen has been found to be extremely surface active in liquid iron in previous investigations reported in literature.

In the case of a dilute solution of a surface active species i in a liquid metal, the fraction surface coverage of i, θ_i, can be related to the bulk activity a_i by the Langmuir Adsorption Isotherm, as follows:

$$\frac{\theta_i}{1 - \theta_i} = K_i\, a_i \qquad [3]$$

where K_i is the adsorption coefficient of i in the liquid metal. Belton combined the Langmuir adsorption isotherm with that of Gibbs to derive an equation that related the depression in the surface tension of a liquid metal to the activity and the adsorption coefficient of the surface active solute present in the metal, as follows:[21]

$$\gamma^{\text{pure}} - \gamma = \mathrm{R}T\Gamma_0^i \ln\,(1 + K_i\, a_i) \qquad [4]$$

where γ_{pure} and γ are the surface tensions of the pure liquid metal and the metal with the surface active element present as a solute, respectively, R is the universal gas constant, T is the temperature in Kelvin, and Γ_0^i is the surface excess of i at the saturation limit. Given the depression in the surface tension of the liquid metal over an activity range of a surface active species, the adsorption coefficient of the surfactant can be determined using the aforementioned equation.

The most recent results of Jimbo and Cramb[6] were used to calculate the adsorption coefficient of oxygen in liquid iron at 1550 °C. A computer program was written to calculate the adsorption coefficient by curve fitting Belton's equation to the experimental data. The adsorption coefficient of oxygen in liquid iron, $K_{\text{O(Fe)}}$, referred to the $P_{\text{CO}_2}/P_{\text{CO}}$ scale, was calculated to be 137. The same parameter was determined by Cramb and Belton,[26] using interfacial kinetics studies, to be 140 on the weight percent O scale, which would translate to 116.5 on the $P_{\text{CO}_2}/P_{\text{CO}}$ scale. The two results are in good agreement, considering the fact that a significant amount of error may be introduced in calculating K_{O} from surface-tension results because of small errors in the surface-tension values. An error in a surface-tension value will be magnified exponentially in the K_{O} value, because of the nature of Belton's equation.

C. *Surface Tension of the Liquid Ni-O System*

There have been fewer studies on the surface tension of liquid nickel as a function of oxygen potential, as compared to liquid iron. The studies by Ogino and Taimatsu[19] and Eremenko and Naidich[20] indicate that oxygen is surface active in liquid nickel, although there is a certain amount of disagreement between the two results. Using the results from the present work, the adsorption coefficient of oxygen in liquid nickel ($K_{\text{O(Ni)}}$) was calculated to be 0.3 on the $P_{\text{CO}_2}/P_{\text{CO}}$ scale, or 10.0 on the weight percent O scale.

The oxygen potential of liquid nickel in the present set of experiments was controlled by the $P_{\text{CO}_2}/P_{\text{CO}}$ ratio of the gas atmosphere. The activity of dissolved oxygen in 1 wt pct standard state was determined from the $P_{\text{CO}_2}/P_{\text{CO}}$ ratios using the following thermodynamic relationship derived by Ichinose:[7]

$$\Delta G^{\circ}_{\;(1/2\text{O}_2\; =\; \underline{\text{O}}\;(\text{wt pct in liquid Ni}))} = -26{,}700 + 5.4T \text{ cal} \qquad [5]$$

However, the previous studies by Eremenko and Naidich[20] and Ogino and Taimatsu[19] express the oxygen level in liquid nickel in terms of oxygen content in weight percent, instead of oxygen activity. The oxygen content of the nickel samples could not be determined in the present work, because the nickel samples were too small in size for an accurate measurement of this quantity. In order to compare the surface-tension results from the present work with those from the previous ones, the oxygen activity levels determined in the present work were converted to oxygen contents in weight percent. A well-known thermodynamic relationship was used, as follows:

$$h_{\text{o}} = f_{\text{o}}\,[\text{weight percent O}] \qquad [6]$$

where h_{O} is the oxygen activity in 1 wt pct standard state and f_{O} is the activity coefficient.

Wriedt and Chipman[27] determined the oxygen solubility in liquid nickel at varying oxygen potentials in the temperature range of 1496 °C to 1700 °C. These results were used to determine the value of f_{O}, by means of interpolation, at 1550 °C. The calculated value of f_{O} was 1.95.

Oxygen contents of nickel samples used in the present work were calculated using this f_{O} value, assuming that the value of f_{O} was constant throughout the range of oxygen variation. Figure 5 is a plot of variation of surface tension of nickel with the oxygen content.

It must be mentioned at this stage that the surface-tension experiments of pure liquid nickel were at first carried out on pure alumina substrates. The X-ray pictures of nickel droplets showed the presence of gas bubbles inside the droplets, and that the droplets had consequently swelled in size. The droplet contours obtained from these experiments had to be discarded because of the presence of the gas bubbles. Swelling of nickel droplets in contact with alumina substrates has been reported earlier.[14] It is possible that liquid nickel reacts with the alumina substrate in these extremely reducing conditions to form a very stable spinel with the evolution of carbon monoxide. The sessile drop experiments were then successfully carried out on magnesia substrates, and no reaction between the two phases could be detected.

Previous investigations of liquid nickel that were performed on alumina substrates were not carried out using an X-ray facility; therefore, the presence of gas bubbles inside

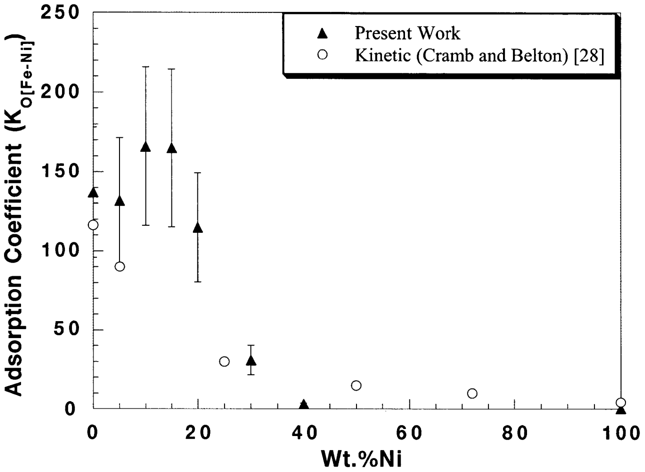

Fig. 12—Variation of adsorption coefficient as a function of alloy composition. The estimated variation in the adsorption coefficient values determined in the present study is about 30 pct.

the droplets could not be detected. It is likely that the droplet contours of liquid nickel recorded in these cases were incorrect, and hence the results from these studies should be treated with caution.

D. *Surface Tension of the Liquid Fe-Ni-O System*

Although the surface tensions of the Fe-O and the Ni-O systems have been determined in the past, no work has so far been done on the iron-nickel-oxygen system. In the present work, surface tensions of liquid iron-nickel alloys were determined at varying oxygen potentials.

The adsorption coefficient of oxygen in the iron-nickel alloy ($K_{O(Fe-Ni)}$) was determined as a function of the nickel content of the alloy. The K_O values, referred to the P_{CO_2}/P_{CO} scale, are plotted as a function of wt pct Ni of the alloy in Figure 12. The $K_{O(Fe-Ni)}$ is nearly constant in the pure iron to Fe-20 wt pct Ni range, and decreases sharply in the 20 to 40 wt pct Ni range. The $K_{O(Fe-Ni)}$ does not change significantly between 40 wt pct Ni and pure nickel. The $K_{O(Fe-Ni)}$ for Fe-40 wt pct Ni alloy is about 3, while that of pure nickel is about 0.3.

Also plotted in Figure 12 are the adsorption coefficients of oxygen in iron-nickel alloys, calculated from the surface-reaction kinetic results obtained by Cramb and Belton.[28] The kinetic studies indicate that the $K_{O(Fe-Ni)}$ values decrease sharply between 0 and 40 wt pct Ni, and remain practically constant between 40 wt pct Ni and pure nickel. The adsorption coefficients obtained from surface kinetic studies show a very similar trend to the ones obtained from the present study, except that the variation of $K_{O(Fe-Ni)}$ in the 0 to 20 wt pct Ni range obtained from the present study is uncertain, possibly attributable to scatter in the data. It is possible that the large amount of scatter in the $K_{O(Fe-Ni)}$ values in the 0 to 20 wt pct Ni range is attributable to errors in surface-tension results in that composition range. As mentioned earlier, even a small amount of error in a surface-tension result will cause a large amount of error in the calculated value of the adsorption coefficient, because of the logarithm term in Belton's equation. It is estimated that a 5 pct variation in surface-tension results will cause about 30 pct variation in the adsorption coefficient values.

V. CONCLUSIONS

Nickel additions to the liquid iron-nickel alloy were found to decrease its surface tension by small amounts at low oxygen potentials. With an increase in the oxygen activity of the system, the surface tension of alloys with nickel contents ranging from 0 to 20 wt pct decreased sharply, indicating that oxygen was highly surface active in these alloys. For metal samples in the composition range of Fe-40 wt pct Ni to pure nickel, the effect of oxygen on the depression of surface tension was much lower than in pure iron. Surface-tension measurements of liquid nickel as a function of oxygen activity indicated that oxygen was surface active in nickel, but to a much lesser extent than it was in liquid iron. The adsorption coefficient of oxygen in iron-nickel alloys was determined as a function of nickel content, and it was found that the adsorption coefficient decreased sharply at 40 wt pct Ni and remained nearly constant between 40 and 100 wt pct nickel. This trend was found to be in accordance with that observed by Cramb and Belton[28] in a separate study, in which adsorption of oxygen was measured in liquid iron-nickel alloys.

Contact angles of iron-nickel alloys were measured on alumina substrates under varying oxygen potentials. At a low oxygen potential, the contact angle of the alloy was found to decrease with nickel additions. As the oxygen potential of the system was increased, the contact angle of the alloy was found to decrease. At higher oxygen levels, the contact angle increased with nickel additions. These contact-angle measurements support the earlier observation that with nickel additions to the iron-nickel alloy, the surface active behavior of oxygen in the alloy decreases.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support of the Center for Iron and Steelmaking Research, Carnegie Mellon University, for the present work. In addition, a portion of the work was sponsored by the NSF through Grant No. MSM-9120669 and the Tie Project No. EEC-9417436.

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