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TITLE: IMPROVED OIL RECOVERY IN MISSISSIPPIAN CARBONATE RESERVOIRS OF KANSAS -- NEAR TERM -- CLASS 2

Cooperative Agreement No.:	DE-FC22-94BC14987
Contractor Name and Address:	The University of Kansas Center for Research Inc.
Date of Report:	June 1, 1999
Award Date:	September 16, 1994
DOE Cost of Project:	$ 3,169,252 (Budget Period 2 05/16/97 -- 07/30/99)
Principal Investigators:	Timothy R. Carr (Program Manager) Don W. Green G. Paul Willhite
Project Manager:	Daniel J. Ferguson, NPTO Tulsa, Oklahoma
Reporting Period:	July 1, 1998 -- September 30,1998

OBJECTIVES

The objective of this project is to demonstrate incremental reserves from Osagian and Meramecian (Mississippian) dolomite reservoirs in western Kansas through application of reservoir characterization to identify areas of unrecovered mobile oil. The project addresses producibility problems in two fields: Specific reservoirs target the Schaben Field in Ness County, Kansas, and the Bindley Field in Hodgeman County, Kansas. The producibility problems to be addressed include inadequate reservoir characterization, drilling and completion design problems, non-optimum recovery efficiency. The results of this project will be disseminated through various technology transfer activities.

At the Schaben demonstration site, the Kansas team will conduct a field project to demonstrate better approaches to identify bypassed oil within and between reservoir units. The approach will include:

- Advanced integrated reservoir description and characterization, including integration of existing data, and drilling, logging, coring and testing three new wells through the reservoir intervals. Advanced reservoir techniques will include high-resolution core description, petrophysical analysis of pore system attributes, and geostatistical analysis and 3D visualization of interwell heterogeneity.
- Computer applications will be used to manage, map, and describe the reservoir. Computer simulations will be used to design better recovery processes, and identify potential incremental reserves.
- Comparison of the reservoir geology and field performance of the Schaben Field with the previously described by slightly younger Bindley Field in adjacent Hodgeman, County.

- Drilling of new wells between older wells (infill drilling) to contact missed zones;
- Demonstration of improved reservoir management techniques, and of incremental recovery through potential deepening and recompletion of existing wells and targeted infill drilling.

SUMMARY OF TECHNICAL PROGRESS BUDGET PERIOD 2

Progress is reported for the period from 1 July 1998 to 30 September 1998. Work in this quarter concentrated on monitoring the incremental recovery of additional mobile oil through targeted infill drilling and completing mass balance calculations for the Schaben Field (Task 2.1).

The material balance study at the Schaben Demonstration Site confirms that the volumetric description of the reservoir-aquifer system together with the natural water drive mechanism is capable of supporting the reported fluid

Appendix A

Material Balance Calculations – Schaben Field

Introduction

The volumetric estimate of original -oil-in-place (OOIP) for the Schaben Field was calculated to be 37.8 MMSTB (Carr and others, 1997). The reservoir at Schaben Demonstration Site has been in production since 1963. Initial reservoir pressure was approximated at 1370 psi by using the DST pressure recordings from the early wells (Carr and others, 1997). PVT properties were generated by using standard correlations. All wells in the Schaben Field produce under artificial lift. The current fluid columns in most wells indicate that the reservoir is producing significantly above the bubble point pressure (calculated at 225 psi). Reported gas production has been negligible and the reservoir assumed to have no gas cap and or significant dissolved gas. The absence of gas is common in reservoirs of central Kansas (Walters, 1958). The main source of energy driving the production from the reservoir comes from the strong natural water drive.

For a reservoir with no gas cap and being driven by an aquifer, the generalized material balance equation gets simplified as:

$$\frac{F}{E} = N + \frac{W_e}{E}$$

where

$$E = E_o + E_{fw}$$

F denotes the underground withdrawal of fluids from the reservoir, E_o represents the change in volume of the oil and the dissolved gas, E_{fw} stands for the connate water expansion and the reduction in pore volume, and W_e stands for the reservoir volume of water that influxes from the aquifer. The initial volume of oil in the reservoir is defined as N. This simplified material balance equation appears as a straight line, with a unit slope, when F/E is plotted against W_e/E and the Y-axis intercept (i.e. N) of this line estimate the OOIP (Figure A1). This estimate of the OOIP should be comparable to that obtained from volumetric calculations if assumptions about the drive mechanism and in the calculation of the aquifer water influx are reasonable. The material balance OOIP is considered to represent the oil volume that contributes to the production and pressure history of the field (Dake, 1994). This is often referred to as the "active" or "effective" initial oil in place in the reservoir. Because the OOIP determined by volumetric calculations includes immobile oil, it is generally higher than determined by material balance. A difference of less than 10% in calculated OOIP is regarded as an acceptable in the industry (Dake, 1994). If the difference in calculated OOIP is significantly different between volumetric and mass balance calculation one may need to reevaluate reservoir parameters (e.g., dimensions, petrophysical properties and cut-offs).

Aquifer Description

Water influx calculations are based on the geological and petrophysical parameters of the aquifer. Incorrect choices of aquifer parameters will result in deviation of the data from the straight line when F/E is plotted against W_e/E. Modifications of the aquifer parameters through a process of "aquifer fitting" can improve the match of observed pressure and production data with the reservoir characterization. Aquifer fitting assumes importance in situations where, as at Schaben Field, little is known about the aquifer geometry and petrophysics. At Schaben Field, very few wells are drilled into the aquifer.

Water influx from very small aquifers can be calculated by time-independent material balance equations. However, for large reservoirs the aquifer boundary takes a finite time to respond to reservoir pressure changes and thus time dependent models such as developed by Hurst and van Everdingen, Fetkovitch, Carter and Tracy, or Allerd and Chen are used to calculate the water influx, W_e (Dake, 1994).

An aquifer model that can match reservoir pressure and production data is generally determined through a process of trial and error. However aquifer models are not unique and problems may persist despite all efforts at aquifer fitting because of incorrect identification of the reservoir drive mechanism. Initial assumptions about the reservoir drive mechanism are indirect, and are based on the pressure and production performance profiles of the reservoir. Identification of reservoir drive mechanism is important to determine aquifer description and definition and also estimate the size of the initial gas cap. Aquifer parameters were not available for Schaben field and were inferred from reservoir parameters (e.g., porosity, permeability, thickness, rock and fluid compressibility). The small numbers of available logs that penetrate the aquifer in the vicinity of Schaben Field were used to estimate the height of the aquifer. The reservoir radius at Schaben was calculated volumetrically and was found to be 7000 feet Carr and others, 1997). The Carter-Tracy method was used for water influx calculations because it is the time-dependent aquifer modeling option available within the reservoir simulator BOAST3.

OOIP

Material balance calculations require adequate field pressure and production profiles along with the PVT data of reservoir fluids. One method to determine the average field pressure is by volume weighting the shut-in pressures within the drainage area of each well. Regular recording of reservoir pressure at each well form the basis of material balance calculations. Unfortunately at Schaben Field, a recorded history of pressure measurements carried out at individual wells is not available. Only current operating water column heights are available for most of the wells. With limited pressure data, it is impossible to obtain the average reservoir pressure through the life of the field. Thus, the material balance calculations were used to generate the average reservoir pressure profile through the life of the field, and to check if the aquifer description and assumed drive mechanism was adequate to support the reported field performance data. As a result the OOIP determined from volumetric calculations was accepted as correct.

The first nine years of production data from Schaben Field were used to generate yearly oil (N_p) and water (W_p) production data along with the calculations for the underground volume withdrawal (F) of fluids. The Carter-Tracy formulation was used to calculate the water influx (W_e) from an infinite aquifer. Initial aquifer parameters were varied within geologic and engineering limits. The resulting plot between F/E versus W_e/E showed a straight line with unit slope and an intercept showing an OOIP value that is lower but within 10% volumetric OOIP (Figure A1). The average reservoir pressure (for the first 9 years) as a result of this match is plotted as the “base case” profile (Figure A2).

Sensitivity calculations were carried out by varying aquifer and reservoir parameters (e.g., aquifer height, reservoir radius, aquifer permeability, and aquifer porosity). In each case, the value of only one of the above parameters was changed. Each in each case the average reservoir pressure profile was generated, so that the resultant F/E versus W height, porosity, permeability, and effective compressibility). In addition a better understanding of the radius of the reservoir at Schaben was obtained.

As typical of older fields in the mid-continent the average reservoir pressure profile for the Schaben field is not available and the mass balance calculations can not be used to validate of the volumetric description of the reservoir. As a consequence the volumetric OOIP is assumed correct and used to calculate an average reservoir pressure profile. The reservoir pressure profile controls the PVT properties of the reservoir fluids and hence the mobility ratios operating during the production life of the field. Changes in average reservoir pressure are indicative of the amount of change occurring in the fluid viscosities.

The material balance calculations were used to check the consistency among different aspects of reservoir description. These calculations tie together the geologic reservoir characterization of the reservoir, the PVT data, production data and available pressure data. The material balance calculations were used to confirm the reservoir drive mechanism and aquifer parameters. The results of the material balance calculations confirm the initial reservoir characterization and refine important input parameters that can be used to revise the full-field reservoir simulation.

References Cited

1997, Carr, Timothy R., G. Paul Willhite, Dana Adkins-Heljeson, Scott Beaty, Saibal Bhattacharya, Evan Franseen, Paul Gerlach, Willard Guy, John Hopkins, W. Lynn Watney, Rodney Reynolds, Shapour Vossoughi, and G. Paul Willhite, Improved Oil Recovery in Mississippian Carbonate Reservoirs of Kansas -- Near Term -- Class 2, USDOE Annual Report DOE/BC/14987-10, 168p. (Available online at http://www.kgs.ukans.edu/PRS/Info/webPubs97-24.html).

1994, Dake, L. P., Practice of Reservoir Engineering: Elsevier, 534p.

1958, Walters, R. F., Differential entrapment of oil and gas in Arbuckle dolomite of central Kansas
Author: AAPG Bulletin, 42, p. 2133-2173.

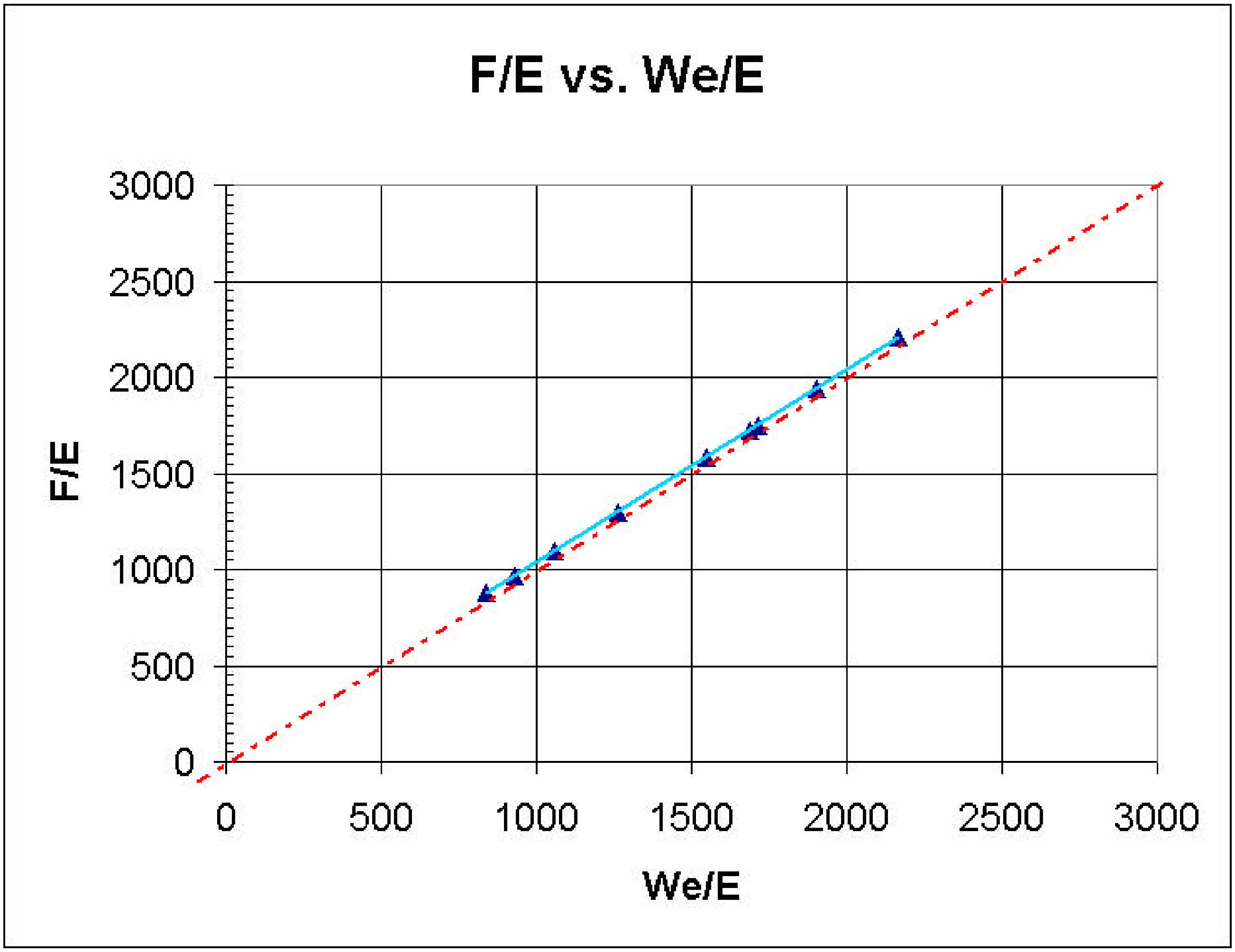

Figure A1. Plot of F/E versus W_e/E showing a straight line with unit slope and an intercept showing an OOIP value that is lower but within 10% of OOIP determined from volumetric calculations (37.8 MMSTB).

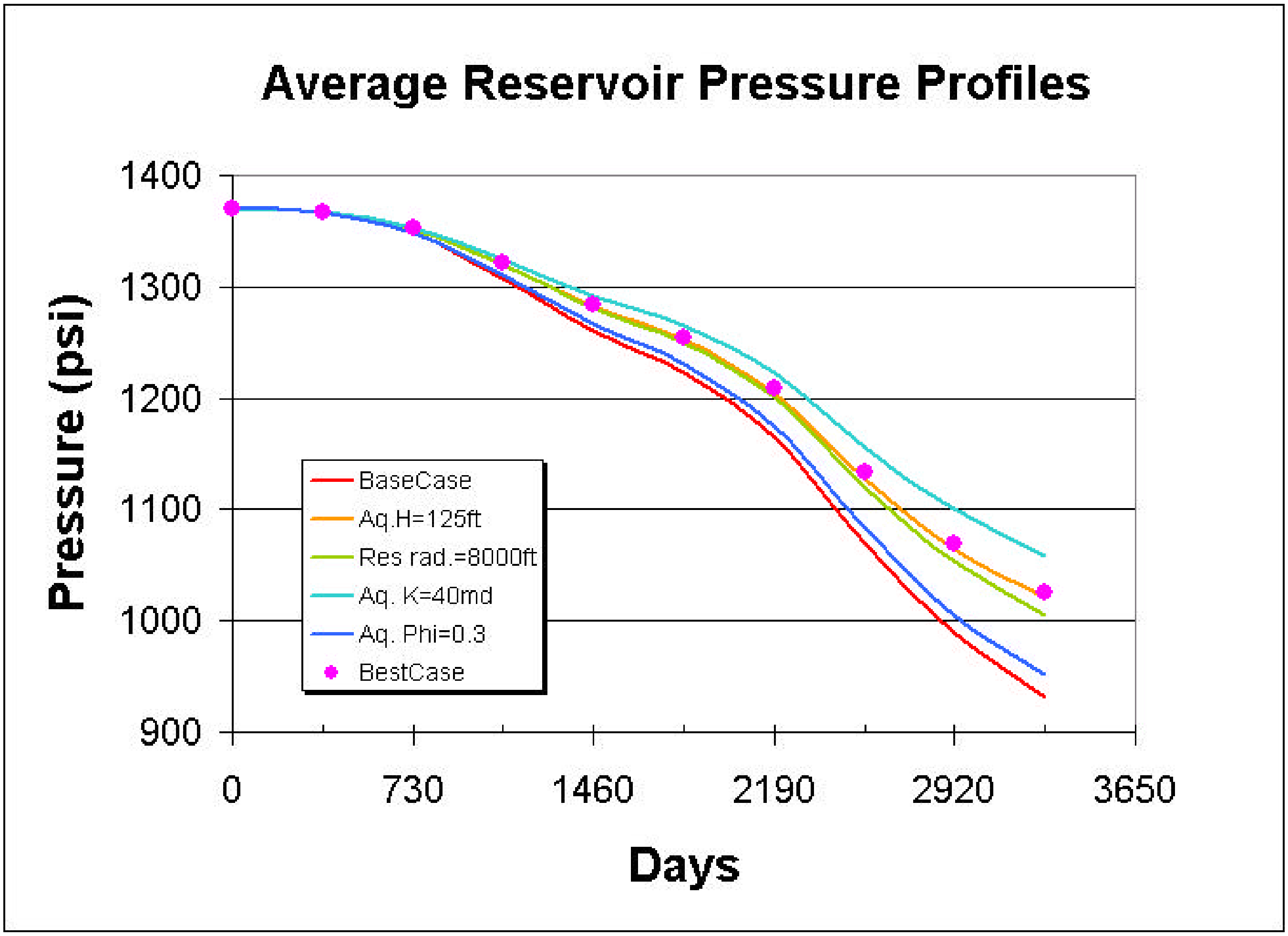

Figure A2. Plot of sensitivity calculations with varying aquifer and reservoir parameters (e.g., aquifer height, reservoir radius, aquifer permeability, and aquifer porosity). In each case, the value of only one parameter was changed. An average reservoir pressure profile was generated, so that the resultant F/E versus W_e/E plot was a straight line with unit slope and its OOIP value was within acceptable tolerances. The plotted pressure profiles show the effects of varying different aquifer and reservoir parameters.

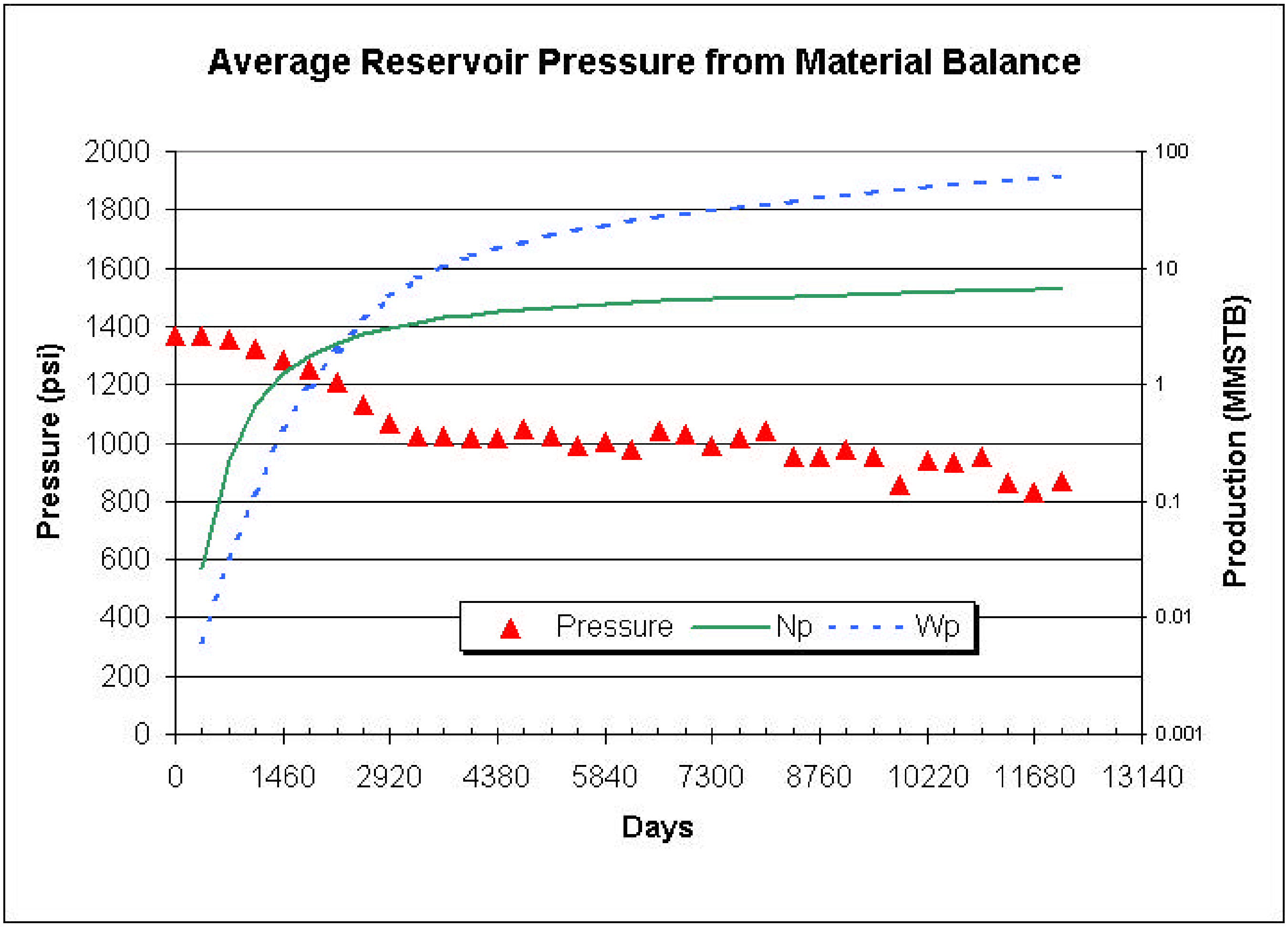

Figure A3. “Best case” scenario for Schaben Field generated over a period of 34 years. Due to the rapid development of the field during the first 9 years, the average reservoir pressure profile shows a rapid decline from 1370 psi to 1000 psi. Subsequent reservoir pressure stabilized near 1000 psi for the next 14 years and then gradually declined to 880 psi over the next 11 years.

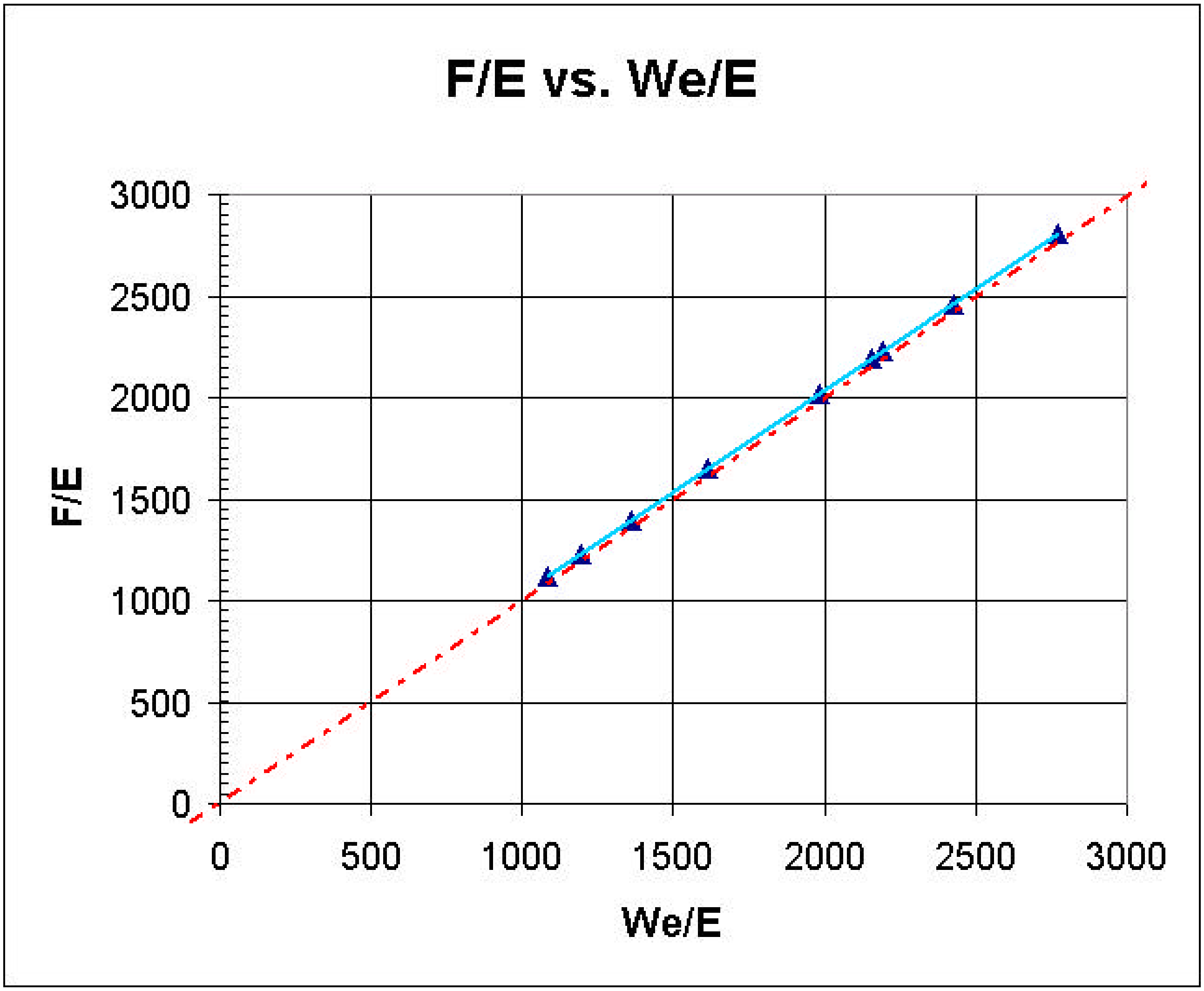

Figure A4. Plot of F/E versus W_e/E for the "best case" scenario remains a straight line with unit slope and its intercept within acceptable tolerances.