is made or it may enter the product during the manufacturing and packaging steps.

LITERATURE CITED

Archer, B. L., Audley, B. G., in "Phytochemistry, Volume II: Organic Metabolites", Miller, L. P., Ed., Van Nostrand-Reinhold, New York, 1973, p 316.
Bonner, J. F., Varner, J. E., "Plant Biochemistry", Academic Press, New York, 1965, p 685.
Crosby, N. T., *Analyst (London)* **102**, 225 (1977).
King, B. G., *Am. J. Dis. Child.* **122**, 337 (1971).
McLaren, J. W., Wheeler, R. C., *Analyst (London)* **102**, 542 (1977).
Perkin-Elmer Corporation, "Model 460 Atomic Absorption Spectrophotometer", Norwalk, CT, 1976.
Perkin-Elmer Corporation, "Analytical Methods Using the HGA 2000 Graphite Furnace", Norwalk, CT, 1977.
Strausbaugh, P. D., Core, E. L., in "McGraw-Hill Encyclopedia of Sciences and Technology", Volume 3, McGraw-Hill, New York, 1977, p 63.
Syty, A., *CRC Crit. Rev. Anal. Chem.* **4**, 155 (1974).

Received for review July 17, 1978. Accepted October 16, 1978.

Cooking Properties of Spaghetti: Factors Affecting Cooking Quality

Roman A. Grzybowski[1] and Brendan J. Donnelly*

The effects of analytical replication, cooking time, and protein quantity and quality on the cooking properties of spaghetti were investigated. Spaghetti cooking quality, as related to cooked weight, cooking loss, and cooked firmness, was determined at specified cooking time intervals. Results showed that replication did not affect analysis and that cooking time was the prime determinant of cooking quality. Protein quantity and quality were also significant factors affecting cooking quality particularly with respect to the maintainance of firmness and cooking stability.

The cooking quality of spaghetti is a measure of its water absorption capacity (cooked weight), cooking loss, and cooked firmness or tenderness. Determination of cooked weight and cooking loss is comparatively simple (Walsh et al., 1971). The objective determination of spaghetti cooked firmness is more difficult. Several techniques have been developed for measuring this quality factor.

Binnington et al. (1939) used a modified Bailey shortometer for measuring the transverse breaking strength of the spaghetti strand and recording tenderness tester for measuring the tenderness of the cooked spaghetti.

Karaesonyi and Borsos (1961) described a torsionmeter for measuring the torsional strength of macaroni and spaghetti.

Walsh (1971) used an Instron Universal Testing Instrument for measuring cooked spaghetti firmness. Cooked spaghetti was placed on a Plexiglas plate and sheared at a 90° angle with a Plexiglas tooth. The work (g cm) used to cut the sample was used as an index of firmness. Statistical analysis of data from replicate determinations showed that the shear test had a high positive correlation ($r = 0.812$) with taste panel scores. Cooking time was 20 min and was selected to place maximum stress on the cooked spaghetti.

Voisey and Larmond (1973) applied the Instron Universal Testing Instrument equipped with tensile test cell, double shear cell, and multiblade test cell. Their results indicated that optimum cooking times for spaghetti ranged from 10 to 18 min and averaged 13 min.

During the spaghetti cooking process the granules imbibe water, swell, and gelatinize. This water penetration and starch gelatinization is dependent on the quality of the surrounding protein network.

According to Holliger (1963), spaghetti containing low protein levels (9%; 14% moisture base (M.B.) imbibed more water and had higher cooking losses than high protein spaghetti (14.1%; 14.0% M.B.). Product shape also affected water absorption and cooking loss. For example vermicelli (diameter 0.9 mm) had a higher water absorption and higher cooking loss than macaroni (diameter 3.6 mm). Holliger also stated (1974) that, in addition to protein content, gluten quantity and quality also influenced pasta product quality.

Sheu et al. (1967) were able to show from reconstitution studies that cooked spaghetti firmness, cooked weight, and cooking loss were primarily affected by the gluten fraction and that starch appeared to have less of an effect on spaghetti cooking quality.

Dahle and Muenchow (1968) noted that protein is an essential structural component of spaghetti and other pasta products. Removal of lipid or protein content adversely affected the retention of amylose. Removal of protein from spaghetti resulted in higher water absorption, higher cooking loss, and greater stickiness, softness, and pastiness.

According to Matsuo and Irvine (1970) the type of gluten in durum wheat had a more pronounced effect on cooking quality than the amount of gluten. A relationship between cooked spaghetti firmness and gluten strength was apparent.

Walsh and Gilles (1971) separated the protein of semolina into albumins, globulins, gliadins, and glutenins. They found that albumin and protein content were negatively correlated with cooking loss and high gliadin content appeared to be related to low cooked weight, low cooked firmness, and high cooking loss.

Irvine et al. (1961) investigated the effect of such factors as wheat type, variety, grade, protein content, particle size, etc. on the farinogram characteristics of semolina. They noted that as protein content increased, dough develop-

Department of Cereal Chemistry and Technology, North Dakota State University, Fargo, North Dakota 58102.
[1]Present address: Department of Food Technology, Agricultural University in Warsaw, Warsaw 02-528, Poland.

0021-8561/79/1427-0380$01.00/0

Table I. Spaghetti Source Material

durum cultivar	wheat protein,[a] %
Wakooma	14.9
Cappelli	13.5
Rugby	13.9
D68139	14.8
D7175	14.5
blend[b]	14.1

[a] Expressed on a 14% moisture basis. [b] Blend (Crosby 50%, Leeds 25%, Ward 25%).

Table II. Spaghetti Source Material

durum cultivar	wheat protein,[a] %	gluten strength[b]
D7169	12.0	1
Rugby	13.6	2
Rolette	14.2	3
DT411	15.4	8
D7158	16.6	7
D71117	17.6	5

[a] Expressed on a 14% moisture basis. [b] Derived from comparison with standard curves.

ment time decreased and the tolerance index increased.

Evans et al. (1975) found that addition of polyphosphate to spaghetti had a detrimental effect on spaghetti cooking quality. The effect was manifested in the gluten network. A reduction of protein matrix cohesion appeared as a retracted protein network, unprotected starch granules, fissures, and crevices. Loss of cohesion caused the reduction of mechanical breaking strength, reduced water absorption, and increased cooking loss.

In this study, the effect of analytical replication and cooking time on spaghetti cooked weight, cooking loss, and firmness were determined. In addition, the cooking properties of spaghetti made from durum wheat containing 12.0 to 17.6% protein were investigated. The effect of gluten strength, as indicated by the farinogram, on cooking quality was noted.

EXPERIMENTAL SECTION

To determine the effect of replication and cooking time on spaghetti cooked weight, cooking loss, and firmness, six durum wheat varieties and two selections (1974 crop year) were used (Table I). The Crosby, Leeds, and Ward blend represents the milling and processing control used in the 1974 North Dakota crop quality evaluation. The other five durums were grown at the Langdon Branch Station in 1974. The range in protein content between all samples is 1.4%.

To determine the effect of protein quantity and quality on cooking quality, two durum wheat varieties and four selections (1975 crop year) were used (Table II).

Cooking Quality. Spaghetti was processed on a DEMACO continuous semi-commercial scale extruder as outlined by Walsh et al. (1971) for optimum overall quality.

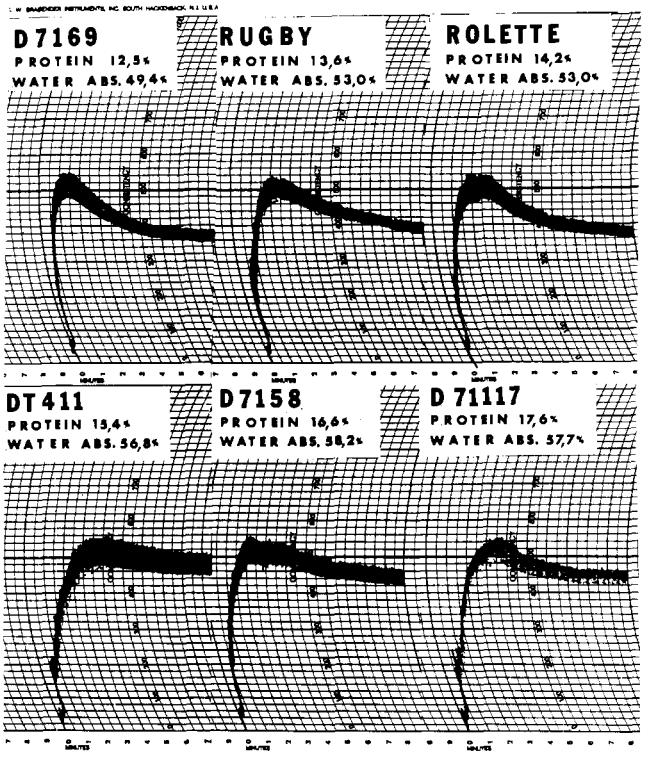

Figure 1. Farinograms of durum wheat selections and varieties.

All spaghetti samples were dried at 40 °C in a laboratory macaroni dryer (Gilles et al., 1966) with an 18-h drying cycle where the relative humidity was lowered in a straight-line gradient from 95% at the beginning to 61% at the end of the drying cycle. The diameter of the dried product ranged from 1.50 to 1.54 mm. After cooking 10 g of spaghetti in 300 mL of boiling distilled water for the designated time interval, the cooked weight, cooking loss, and cooked firmness were determined by the methods of Walsh and Gilles (1971). Cooked weight (g) is a measure of the water absorbing capacity of the spaghetti. Cooking loss (%) is the quantity of material lost to the water during cooking and cooked firmness (g cm) is the force required to bisect the cooked spaghetti strand using the Instron Universal Testing Instrument.

Farinograms. Farinograms were obtained on the semolina milled from the samples grown in 1975 using the AACC Approved Methods (1962). The resulting curves are shown in Figure 1. Gluten strength, derived from comparison of these curves with standard curves, developed in this laboratory is indicated in Table II by numbers 1 through 8 with the higher numbers 7 and 8 indicating strong gluten characteristics.

RESULTS AND DISCUSSION

The main objective of the preliminary analysis was to determine the effect of replication and cooking time on the

Table III. Effect of Cooking Time on the Cooking Properties of Spaghetti[a]

cooking time, min	cooking loss,[b] %	stand. dev.	cooked weight,[b] g	stand. dev.	cooked firmness,[b] g cm	stand. dev.
5	4.2	0.14	22.70	0.35	9.4	0.5
10	5.6	0.26	28.12	0.39	6.0	0.3
15	6.7	0.24	32.46	0.37	4.8	0.2
20	7.9	0.27	36.40	0.65	4.1	0.2
25	8.4	0.48	39.80	0.27	3.5	0.2
30	9.3	0.37	42.62	0.54	3.2	0.1

[a] Combined results for Wakooma, Cappelli, Rugby, D68139, D7175, and blend. [b] Values represent means of six samples (five replications).

Table IV. Correlation Coefficients between Cooking Quality and Cooking Time, Variety, Protein Value, and Replication

variable	correlation coeff.
cooked weight vs. cooking time	0.98[a]
cooked weight vs. variety	0.005
cooked weight vs. protein	0.005
cooked weight vs. replication	0.03
cooking loss vs. cooking time	0.94[a]
cooking loss vs. variety	−0.05
cooking loss vs. protein	−0.10
cooking loss vs. replication	0.10
firmness vs. cooking time	−0.87[a]
firmness vs. variety	−0.02
firmness vs. protein	−0.02
firmness vs. replication	0.04

[a] Significant at 1% level of confidence.

cooking quality of spaghetti.

Five replicate analyses of the cooking test were used with six samples. The cooking times in boiling distilled water were 5, 10, 15, 20, 25, and 30 min and the cooked weight, cooking loss, and cooked firmness for the combined data on all samples are shown in Table III. The table shows that as cooking time increases, cooked weight and cooking loss increased almost linearly between 10 and 25 min, and the firmness values drop off exponentially. For all samples the optimum requirements for good cooking quality with minimal deviation about its mean is apparent at 15-min cooking time. Statistical analysis showed that replication did not affect the analysis and that the predominant effect on spaghetti cooking quality was cooking time (Table IV).

Effect of Protein Quantity and Quality. Further experimental data was obtained on a series of samples having a greater range in protein content to better determine the overall effect of protein quantity and quality on spaghetti cooking quality. The results are shown in Table V. The correlation coefficients between spaghetti cooking quality and cooking time, protein content (14% moisture basis), and gluten strength are shown in Table VI. Again the correlation coefficients show a highly significant relationship between cooking quality and cooking time.

It was also noted that protein content and gluten strength were significantly correlated (0.1% confidence level) with cooking loss and cooked firmness, respectively. There was no significant relationship between these factors and cooked weight. However, an analysis of the Duncan multiple range test (5% level of confidence) showed that there was a significant difference in cooked weight between the pasta processed from selection D7169 and the five other samples (Table VII). Rugby, Rolette, and D7158 were not significantly different but there was a significant difference between these three samples and DT411 and D71117. These results are in line with those of Dahle and Muenchow (1968).

As indicated in Table V there was a significant inverse relationship between both protein content and gluten strength with cooking loss. The Duncan multiple range test showed a significant difference in cooking loss between D7169 and the other samples (Table VIII). Rugby and Rolette were significantly different from the other samples as were Rolette and D71117. The pasta from selections DT411 and D7158 were similar in cooking loss but different from the others. The least cooking loss was exhibited by both D7158 and DT411 which have lower protein levels than D71117. It is apparent that high protein content per se is not a determinant of spaghetti cooking loss and this corroborates Sheu's (1970) results

Table V. Cooking Properties of Spaghetti Processed from Durum Wheat Varieties

sample	protein,[a] %	gluten[b] strength	cooked weight, g[c]				cooking loss, %[c]				cooked firmness, g cm[c]			
			cooking time, min				cooking time, min				cooking time, min			
			5	10	15	20	5	10	15	20	5	10	15	20
D7169	12.0	1	24.62	31.03	37.79	41.26	5.4	7.3	8.4	9.4	6.25	3.64	3.16	2.86
Rugby	13.6	2	23.46	28.48	34.03	36.78	4.0	5.5	6.9	7.9	9.00	6.15	4.85	4.02
Rolette	14.2	3	23.36	28.46	33.28	38.00	3.2	5.6	7.1	7.8	11.22	6.53	5.03	4.41
DT411	15.4	8	22.52	27.73	32.40	36.66	4.0	4.9	6.0	6.6	11.00	8.10	6.31	5.35
D7158	16.6	7	23.14	28.92	33.26	37.11	3.9	5.3	6.0	7.0	10.76	7.35	5.89	5.51
D71117	17.6	5	22.70	27.95	32.62	36.11	4.0	5.5	6.8	7.5	11.39	8.02	5.55	4.47

[a] Expressed on a 14% moisture basis. [b] Derived from comparison with standard farinograms. [c] Average of two replications.

Table VI. Correlation Coefficients between Cooking Quality and Cooking Time, Protein, and Gluten Strength

variable	correlation coeff.
cooked weight vs. cooking time	0.96[a]
cooked weight vs. protein	−0.18
cooked weight vs. gluten strength	−0.17
cooking loss vs. cooking time	0.85[a]
cooking loss vs. protein	−0.37[a]
cooking loss vs. gluten strength	−0.40[a]
cooked firmness vs. cooking time	−0.79[a]
cooked firmness vs. protein	0.44[a]
cooked firmness vs. gluten strength	0.44[a]

[a] Significant at 1% level of confidence.

Table VII. Duncan Multiple Range Test for Cooked Weight[a]

variety	protein	cooked weight, g
D7169	12.0	+
Rugby	13.6	+
Rolette	14.2	|
D7158	16.6	+
D71117	17.6	+
		|
DT411	15.4	+

[a] Significant at 5% level of confidence.

Table VIII. Duncan Multiple Range Test for Cooking Loss[a]

variety	protein	cooking loss, %
D7169	12.0	+
Rolette	14.2	+
		|
Rugby	13.6	+ +
		|
D71117	17.6	+
D7158	16.6	+
		|
DT411	15.4	+

[a] Significant at 5% level of confidence.

Table IX. Duncan Multiple Range Test for Cooked Firmness[a]

variety	protein	cooked firmness
DT411	15.4	+
D71117	17.6	|
D7158	16.6	+
Rolette	14.2	+
Rugby	13.6	+
D7169	12.0	+

[a] Significant at 5% level of confidence.

which showed that such residue is a function of gluten quality.

As for the effect of protein content on cooked spaghetti firmness, it can be seen from both Tables V and IX that the cooked firmness of the pasta from low protein selection D7169 is significantly lower than all the other samples. The higher protein selections DT411, D71117, and D7158 were not significantly different in their overall cooked firmness values. The firmness scores of the spaghetti from these three selections at the 15-min cooking time (Table V) were at "al dente" levels deemed desirable by prior taste panel studies (Walsh, 1971). It was also noticed that cooking for an extra 5 min did not move the "al dente" requirements of these three samples outside the acceptable level whereas the lower protein samples continued to lose their tenderness becoming quite soft. Although there was no significant difference in cooked firmness between DT411, D7158, and D71117 it is apparent from Table V that as cooking time increased beyond 15 min the firmness scores of DT411 and D7158 were essentially the same, whereas that of D71117 dropped significantly below these two. Again the effect of protein content vs. protein quality is apparent. The relationship between the farinogram data of these samples and their respective cooking quality after 15-min cooking are shown in Table X. Here it is evident from the mixing tolerance index (MTI), dough development time (DDT), and stability data that of the samples listed, selection DT411, with a protein content of 15.4%, had the highest gluten strength and most desirable characteristics for cooking quality. As pointed out by Irvine et al. (1961), gluten strength is associated with reasonably high protein content and protein quality. The data in Table X clearly show this variability in protein quantity and quality between these selections and varieties and substantiates the relationship between gluten quality and spaghetti cooking properties.

CONCLUSIONS

The cooking quality of spaghetti processed from different durum wheat selections and varieties were examined. It was found that replication did not affect the data and that the overriding factor involved in spaghetti cooking quality was cooking time. Protein quantity and quality were also significant factors with respect to cooking quality. High protein content did not necessarily mean optimum cooking quality as was evidenced by the comparison between DT411 and D71117. A correlation of the cooking data with semolina farinograms clearly indicated the importance of gluten strength. The cooking data also indicated that spaghetti cooking time should not be more than 15 min. Cooking times beyond that point clearly have a deleterious effect on spaghetti cooking quality particularly with low protein, weak gluten samples. The stronger gluten spaghetti had greater cooking stability as evidenced by the maintenance of good cooked firmness scores at the 20-min cooking time.

As Grzybowski and Donnelly (1977) pointed out, these results hold true for spaghetti strands 1.52 mm thick.

Table X. Farinogram Data and Spaghetti Cooking Quality[a]

variety	protein content, %	water absorb., %	dough develop time, min	tolerance index, B.U.	stability, min	cooking quality: cooked weight, g	cooking quality: cooking loss, %	cooking quality: firmness, g cm
D7169	12.0	49.4	1.5	150	1.5	37.79	8.4	3.16
Rugby	13.6	53.0	2.0	100	2.0	34.03	6.9	4.85
Rolette	14.2	53.0	2.0	120	2.0	33.28	7.1	5.03
DT411	15.4	56.8	4.0	40	8.0	32.40	6.0	6.31
D7158	16.6	58.2	3.5	80	4.0	33.26	6.0	5.83
D71117	17.6	57.7	3.5	90	3.5	32.62	6.8	5.55

[a] Cooking time, 15 min.

Obviously thinner or thicker strands are going to display different cooking qualities.

LITERATURE CITED

American Association of Cereal Chemists, "AACC Approved Methods", 7th ed, The Association, St. Paul, Minn., 1962.
Binnington, D. S., Johannson, H., Geddes, W. F., *Cereal Chem.* **2**, 149 (1939).
Dahle, L. K., Muenchow, H. L., *Cereal Chem.* **45**, 464 (1968).
Evans, G. C., deMan, J. M., Rasper, V., Voisey, P. W., *Can. Inst. Food Sci. Technol. J.* **8**, 102 (1975).
Gilles, K. A., Sibbitt, L. D., Shuey, W. C., *Cereal Sci. Today* **11**, 322 (1966).
Grzybowski, R. A., Donnelly, B. J., *J. Food Sci.* **42**, 1304 (1977).
Holliger, A., *Cereal Chem.* **40**, 231 (1963).
Holliger, A., *Buhler Diagram* **37**, 64 (1974).
Irvine, G. N., Bradley, J. W., Martin G. C., *Cereal Chem.* **38**, 153 (1961).
Karaesonyi, L. P., Borsos, A. C., *Cereal Chem.* **38**, 14 (1961).
Matsuo, R. R., Irvine, G. N., *Cereal Chem.* **47**, 173 (1970).
Sheu, R-Y., Medcalf, D. G., Gilles, K. A., Sibbitt, L. D., *J. Sci. Food Agric.* **18**, 237 (1967).
Voisey, P. W., Larmond, E., *Cereal Sci. Today* **18**, 126 (1973).
Walsh, D. E., *Cereal Sci. Today* **16**, 202 (1971).
Walsh, D. E., Ebeling, D. A., Dick, J. W., *Cereal Sci. Today* **16**, 385 (1971).
Walsh, D. E., Gilles, K. A., *Cereal Chem.* **48**, 544 (1971).

Received for review September 12, 1977. Accepted September 11, 1978. Published with the approval of the Director, North Dakota State Agricultural Experiment Station, Fargo, North Dakota, as Journal Series No. 944.

Catalytic Effects of Stainless Steel, Teflon, or Glass on Thermal Degradation of Thiamin in a Tubular Laminar-Flow Reactor

Joseph W. Bell,* Peter R. Rony, Warren K. Stone, and William F. Collins

A tubular laminar-flow reactor was designed to measure the effects of contact surfaces on the kinetics of thermal degradation of thiamin. The catalytic effects of polished type 321 stainless steel, Teflon, and Pyrex glass were determined in a phosphate–citrate buffer at pH 6.60 from 70–90 °C. The rate constants were not significantly different. Thus thiamin breakdown occurred in the homogeneous liquid phase and not on the walls of the reactor.

New processing procedures and packaging materials are introduced primarily to improve quality and increase shelf life of food products. During thermal processing, fluid foods come in contact with the surface of the processing equipment at high temperatures. In storage they may remain in contact with the packaging material under reduced refrigeration for extended periods of time. These exposures could catalyze chemical deterioration of some food constituents thereby lowering quality and nutritional value. There is an urgent need for information on the catalytic effects of processing and packaging materials on the degradation of food constituents.

Pratt (1930) was among the first to study the effects of a contact surface on the stability of vitamins. He measured leaching from a nickel pasteurizer into milk and determined the effects of increased nickel content on stability of the B vitamins. However, owing to a lack of appropriate instrumentation, decisive conclusions were not made. Farrer (1947a) reported that thiamin degradation was catalyzed by iron, zinc, and nickel in a phosphate–citrate buffer, but not in a phosphate buffer. He suggested that catalysis was due to the formation of a complex between the metallic ions and citrate. Copper acted differently from the other ions, catalyzing thiamin degradation in phosphate buffer and retarding its destruction in phosphate–citrate buffer below pH 6.5. He suggested that this retarding effect was due to a complex between copper and citrate.

Department of Food Science and Technology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061.

Factors affecting thiamin stability have been widely studied. Windheuser and Higuchi (1962) published an excellent review of the kinetics of thiamin degradation as affected by buffer salts and pH. Dwivedi and Arnold (1972) and Windheuser and Higuchi (1963) reviewed the effects of other compounds on the thermal stability of thiamin.

Thiamin degradation has been studied in the presence of several different contact surfaces and under diverse conditions. Thiamin solutions have been autoclaved in lacquer-lined cans (Morfee and Liska, 1971, 1972) and in glass vials (Dwivedi and Arnold, 1972, 1973; Dwivedi et al., 1972); sealed in glass tubes and immersed in hot water (Arnold et al., 1969; Windheuser and Higuchi, 1962, 1963; Beadle et al., 1943; McIntire and Frost, 1944); boiled and refluxed in glass systems (Booth, 1943; Farrer, 1945a,b, 1947a,b, 1948, 1953, 1955; Farrer and Morrison, 1949); and injected directly into a steam-filled stainless steel chamber (Mulley et al., 1975a,b). The different kinetic parameters reported in these studies may be attributed partly to the catalytic effects of the contact materials on thiamin degradation. Published information is lacking on effects of contact surfaces on the kinetic parameters of thiamin degradation. This study was undertaken to determine the effects of type 321 stainless steel, Teflon (FEP from Supelco, Inc., Bellefonte, Pa), and Pyrex glass on the catalyzed degradation of thiamin hydrochloride in a phosphate–citrate buffer at pH 6.60.

MATERIALS AND METHODS

Apparatus. A catalytic reactor was designed and assembled for this study (Figure 1). The electronic units, A and B, controlled the speed of the high-pressure pumps,

0021-8561/79/1427-0384$01.00/0