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Parametric Performance Studies on
Fluidized-Bed Heat Exchangers

Quarterly Technical Progress Report
28 July Through 30 September 1981
Contract DE-AC22-81-PC04280

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ABSTRACT

Analyses and experiments will be performed in this program to investigate the performance of single- and multi-stage shallow fluidized beds for possible application to the recovery of heat from sources such as waste heat, and coal combustion or coal gasification. This work is an extension of work done previously under Contracts EC-77-C-03-1433 and DE-AC03-79-ET11348. In this program, tests will be conducted to (1) investigate the effects of fouling due to liquid condensate in the gas stream on fluidized bed heat exchanger performance, (2) investigate the performance of fluidized beds which are staged using baffle plates, and (3) investigate the effects of different heat exchanger surface geometries. During the quarter ending 30 September 1981, work progressed in selecting the conditions for that portion of the program involving fouling by a liquid condensate. Modifications were made to the Fluidized Bed Heat Exchanger Facility for the fouling experiments and plans were developed for the preliminary tests in those investigations.

INTRODUCTION

During the quarter ending 30 September 1981, this Contract (DE-AC22-81-PC40280) was initiated. Under this contract, three aspects of Fluidized Bed Heat Exchangers are to be experimentally studied: viz. (1) the effects of fouling; (2) the effects of horizontal baffles; and (3) the effects of surface geometry. The first year of this two-year contract is devoted primarily to the study of the fouling characteristics of fluidized bed heat exchangers.

In many applications involving the exchange of heat across a surface, fouling of that surface can greatly reduce the effectiveness of the heat exchanger. Fouling the heat exchanger surface may be by both liquid or solid particle buildup on the surface. Solid particles, for instance, may be present in the exhaust stream from a coal combustor or a diesel, while liquid condensate could occur in the heat exchanger in the exhaust from a coal gasifier, coal dryer, or a waste heat recovering device.

A fluidized bed heat exchanger is purported to be resistant to solid particle fouling because of the scrubbing action of the particles on the heat exchanger surface. This was demonstrated to some extent in Ref. 1, and to a greater extent in Ref. 2, although in the latter case some fouling of the distributor plate did occur, but was easily removed. Thus, solid particle fouling appears to be much less of a problem with fluidized bed heat exchangers than does fouling by a condensible vapor. If the liquid condensate is sticky and wets the particles, agglomeration will eventually occur, destroying the fluidity. If the condensation is at a low enough rate, it should be possible to continuously remove some particles from the bed, clean, and replace the particles, thus maintaining a deagglomerated bed.

It is the objective of this portion of the investigation to study the effects of liquid condensate fouling in a laboratory-scale fluidized bed heat exchanger. The United Technologies Research Center (UTRC) Fluidized Bed Heat Exchanger Facility, described in Ref. 1, will be used in this investigation. A sketch of this facility is shown in Fig. 1.

TECHNICAL DISCUSSION

Progress for Quarter Ending 30 September 1981

In Task 1 of this project, fouling characteristic experiments are to be performed in which a condensible vapor is injected into the gas stream upstream of the distributor plate. (The present UTRC Fluidized Bed Facility can maintain a 260 C (500 F) air inlet temperature.) The heat exchanger in the fluidized bed will be adjusted so as to reduce the gas temperature within the bed to below the liquid condensation temperature (i.e., dew point). Tests will be conducted with at least two (2) different condensible vapors: one will be a vapor that when condensed results in a low viscosity liquid that will tend not to agglomerate the particles; in the other test a vapor will be used that when condensed gives a highly viscous "sticky" liquid that will "wet" both the particles and the distributor. In the first case, water vapor appears to be a good candidate, while the highly viscous condensate would result, for example, from condensing a vapor that would occur in the drying process of a hydrocarbon resin.

During the preceding quarter, work was directed toward the selection of condensible vapors, preliminary design of a vaporizer, and modifying the existing UTRC Fluidized Bed Heat Exchanger (FBHEX) for the fouling experiments. Water, glycerol, and the refrigerant Freon 11 (CCl_3F) were studied as condensible vapor candidates for the fouling experiments. Some properties of these compounds such as boiling point, viscosity, and surface tension are tabulated below.

<u>Compound</u>	<u>Boiling Temp., °C (°F)</u>	<u>Viscosity Centipoises</u>	<u>Surface Tension- Dyne/Cm</u>
Water	100 (212)	1.0	72.8
Glycerol	290 (554)	380	63.5
CCl_3F	23.9 (75)	0.42	18.0

Glycerol has approximately the same surface tension as water but is more viscous by a factor of 380. CCl_3F is less viscous than water by a factor of 2.4, and its surface tension is less than that of water by a factor of 4.

Calculations showed that a single vaporizer can be used to supply the FBHEX with either water or glycerol vapor provided heating coils having wattages less than about 3.1 W/sq cm (20 W/sq in.) are used in the vaporizer (higher wattages cause charring at the glycerol). Approximately 30 kW of power

are required to supply the FBHEX with inlet air having 0.05 kg of water per kg of air with a dew point of 40.6 C (105 F) or 0.02 kg of glycerol per kg of air with a dew point of 148.9 C (300 F). Typical calculated FBHEX flow rates, temperatures, and heating requirements for tests with water and glycerol vapors are tabulated below. The calculations were based on previously measured values of heat transfer coefficients (Ref. 1) between the fluidized bed and the finned tube heat exchanger and were obtained with no condensate present.

Condensate	Air Flow Rate (kg/s)	Inlet Air Temp. (°C)	Air Heating Req'd. (kW)	Vapor Flow Rate (kg/min)	Inlet Dew Point (°C)	Outlet Air Temp. (°C)	Coolant Bulk Temp. (°C)	Cond. Flow Rate (kg/min)	Temp. HEX Sur. (°C)	Superficial Velocity (cm/sec)
Water	0.18	93	12	0.55	40.6	45	18.3	0.27	29	36.6
Glycerol	0.23	177	34	0.23	160	57.2	18.3	0.23	31	54.9

Calculations were also performed to determine if Freon 11 (CCl_3F) would be a candidate condensate. If Freon 11 were selected as one of the condensible vapors with water or glycerol as the other, both a vaporizer and a refrigerator would be required since the coolant temperature would have to be lower than the available water supply temperature. Therefore, most of the fouling tests will be done using water and glycerol as the condensible vapors. Data from these tests will be used to determine the effect of large differences of viscosity of fouling (viscosity of water and glycerol is 1.0 and 380 centipoises, respectively). However, since the surface tensions of water and glycerol are similar (72.8 and 63.5 dynes/cm, respectively), the data from these tests will not provide information concerning the effects of surface tension. Investigations are continuing to find a liquid with a higher surface tension that could be used in limited tests in the existing FBHEX. Preliminary studies suggest Freon 113 ($\text{C}_2\text{Cl}_3\text{F}_3$) with a boiling point of 48 C (118 F) may be a viable alternate providing its toxicity is acceptable. Further investigation of Freon 113 is continuing.

In the proposed program, the vapor pressure of the condensates upstream and downstream of the FBHEX was to be measured using a mass spectrometer. However, measurement of water vapor partial pressure by a conventional mass spectrometer can be highly inaccurate due to water vapor adsorption on the steel surfaces, and other instrumentation will be required if water vapor is chosen as one of the condensible vapors. Information on the Panametrics water vapor detector indicates that, with modifications, this instrument may be suitable. Efforts are now in progress to obtain further details about the detector and to determine if it is suitable for glycerol vapor detection; if not, then a mass spectrometer would be used in tests using glycerol.

In previous tests, the FBHEX was operated with the airflow recirculated at flow rates between 0.23 (0.5) and 0.68 kg/sec (1.5 lb/sec). In the fouling experiments, the FBHEX may be operated without recirculation of the air, and the air flow rate for these experiments will be about 0.23 kg/sec (0.5 lb/sec) or less (superficial velocities of 30.5 to 61 cm/sec (1.0 to 2.0 ft/sec), the optimum for heat transfer. To insure accurate measurement of flow at these air flow rates, an ASME long radius flow nozzle replaced the 6 in. orifice plate previously used to measure air flow rate. The corrugated flexible ducting has been replaced with schedule 10 pipe to adhere to ASME standard practice.

Work has been initiated to modify the data reduction program to include changes in the calculation of the air mass flow rate associated with the use of an ASME nozzle in the air metering circuit and to include calculations related to condensible vapors. The data reduction program will be used with the Texas Instrument TM 990 microprocessor and Silent 700 ASR electronic data terminal which were used previously for data reduction in this program.

The FBHEX experiment is being relocated within UTRC in accordance with reassignment of laboratory space. Approximately 90 percent of the work required to relocate the FBHEX experiment is completed. This move is being made at no cost to the Government and will have no affect on the work done under this contract.

Progress Planned for Quarter Ending 31 December 1981

During the next quarter, the FBHEX will be modified for experiments with condensates in the gas flow. The condensates will either be injected as vapors or liquids upstream of the FBHEX bed region. If the condensate is injected as a liquid, a spray bar will be used to atomize and thus enhance evaporation of the liquid. Initially tests will be conducted using water as the condensate. During these tests, the performance of the FBHEX will be monitored. Changes in performance and visible changes in the operation of the fluidized bed will be noted. Also during this next quarter, methods will be incorporated for continuously removing bed material which is contaminated with condensate and adding clean bed material.

REFERENCES

1. Stoeffler, R. C.: Enhancement of Heat Transfer in Waste-Heat Heat Exchangers. United Technologies Research Center Report R80-914653-5, Prepared Under U.S. Department of Energy Contract DEAC03-77-ET11348, July 1980.
2. Cusdin, D. R. and M. J. Virr: A Marine Fluidized Bed Waste Heat Booster. Transactions of Institute of Marine Engineers, Vol. 91, 1979, pp 1-2.

DETAILS OF UTRC FLUIDIZED BED HEAT EXCHANGER MANUFACTURED BY STONE-PLATT FLUIDFIRE LTD

FIG. 1